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EVALUATION OF THE TECHNOLOGY FOR DETECTING SMALL OBJECTS AT SEA SURFACE SENSOR PLATFORMS

Prepared for the Transportation Development Centre,
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BY

B. R. Dawe

D. J. Finlayson

R. A. Stacey

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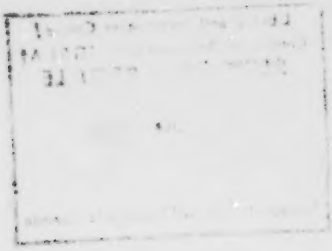

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17. Abstract Shipborne remote sensing techniques for the detection of small objects on the sea surface in a search and rescue situation have been reviewed. Typical targets (20 m length) have been identified together with the 50% and 25% exceedence environmental conditons for typical regions off the east coast of Canada. Remote sensing technologies included in the assessment are infrared, low light level TV, marine X- and S-band radar, and underwater acoustic systems. In each case, the basic operating principles are summarized together with comments on potential operational limitations (such as the effect of ship motion), and available information on the performance of the sensors in detection of small objects, both with and without target enhancement aids (such as radar reflectors). Search sweep widths have been computed for average and severe environmental conditions and used as a basis for assessing the potential usefulness of the remote sensing techniques. Experimentally based sweep widths are only available for marine radars, and only for sea states less than those likely to be encountered off the east coast of Canada. Therefore, information on detection ranges for the various sensors were used to simply rank their potential effectiveness as a function of increasing sea state. It was concluded that the radar was the most effective sensor when visual search was ineffective, with infrared for short range detection at night. Underwater acoustic systems appear to have short-range detection capabilities that are less degraded by increasing sea state than other sensors. An experimental program is recommended for determination of sweep widths for visual and radar searches under typical Canadian environmental conditions. It is further recommended that such tests utilize United States Coast Guard experiment methodology as far as possible.

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17. Résumé Ce rapport rend compte de la recherche sur les systèmes embarqués de télédétection de petits objets flottant à la surface de la mer. Il définit les cibles (moins de 20 m de long) à détecter dans les conditions climatiques types correspondant à des situations décrites comme moyennes (50 p.100 de probabilité de dépassement) et difficiles (25 p.100) régnant au large de la côte Est. Les techniques recensées ont été le capteur à infrarouge, la télévision à faible niveau de luminosité, les radars de marine dans les bandes X et S et le sonar. Le principe fondamental de chaque système est appliqué en donnant en même temps les facteur susceptibles d'en dégrader les performances (les mouvements du navire, par exemple). Il renseigne sur l'aptitude des divers capteurs à détecter les objets visés, avec et sans aide extérieure telle que les réflecteurs radar. La largeur du couloir balayé par chacun des systèmes considérés a été calculée pour les deux situations décrites, afin de servir de critère de comparaison. On ne dispose de données expérimentales que dans le cas des radars de marine et pour des états de mer inférieurs à ceux qui règnent le plus souvent au large de la côte Est. L'information sur les portées utiles n'a donc servi qu'à classer chaque système d'après son efficacité face à des états de mer de force croissante. Le rapport montre que le radar est la technique la plus efficace lorsque la détection visuelle cesse d'être possible, le capteur IR étant particulièrement utile la nuit sur de courtes distance et il est moins influencé que les autres par des états de mer de force croissante. Le rapport recommande un programme de recherche expérimentale visant à déterminer les largeurs de couloirs balayés en détection tant visuelle que radar dans les conditions climatiques définies. Il préconise en outre que ce programme se fonde autant que possible sur la méthodologie mise au point par la Garde côtière américaine.

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EXECUTIVE SUMMARY

The objective of this project has been to assess currently available remote sensing techniques for the detection of small objects on the surface of the ocean. Two parallel studies were commissioned by the Transportation Development Centre (TDC): one by Bercha and Associates of St. John's to evaluate airborne sensor systems, and a second, which is the subject of this report, by NORDCO Limited of St. John's to evaluate the effectiveness of shipborne remote sensing systems.

Small targets were defined as less than 20 metres (m) in overall length, and included vessels, buoys, oceanographic equipment, persons in the water (PIW's), and debris. Factors such as the shape, size, colour, construction material and detection aids that the target might carry were documented. For the sensor performance analysis four representative targets were selected: 15 m and 7 m vessels, a liferaft and a PIW. Average (50 percent exceedence) and severe (25 percent exceedence) environmental operating conditions have been defined for representative marine forecast areas in the Gulf of St. Lawrence, two areas on the Scotian Shelf, two areas on the Grand Banks, one off Labrador and another off Baffin Island. Average sea conditions generally correspond to sea states 2-3 in the summer and 4-5 in the winter. Severe conditions correspond to sea states 4 in the summer and 5-6 in the winter, noting that the presence of ice is an additional factor in the northern areas during the winter and spring months.

Sensors included in the assessment were forward looking infrared (FLIR) and low light level TV (LLLTV) systems,

marine X- and S-band radars, and underwater acoustic systems. In each case, the basic operating principles of the systems are described, and there is a discussion of factors, such as ship motion, that are likely to degrade the performance of the various sensors. Information on sensor performance in detection of the respresentative targets identified earlier has been obtained from published reports, manufacturers' specifications, interviews with operators, and others, and theoretical modelling.

It was concluded that FLIR systems showed promise in sea states less than 3 without stabilization and were equally effective during the day or night. Detection ranges for 10 m targets have been reported to be 3 to 5 kilometres (km). However, FLIR system performance is degraded by precipitation and fog. Active LLLTV is better than passive, and bright lights, rain and fog will degrade the performance of both systems. Extensive experimental work by the United States Coast Guard (USCG) has demonstrated standard radar marine systems can be as good or better than visual searches for small vessels in sea states up to 2, but less effective for extremely small targets, such as PIW's. Under the conditions of the USCG experiments (sea states 0 to 2) marine radar could be considered an effective search aid in darkness, light rain and fog. Theoretical modelling of marine radar performance under higher sea states indicates performance degrades rapidly above sea state 3, but that signal processing can significantly improve conventional marine radar performaance. Equipping targets with detection aids, such as lights or reflective material for visual search, and radar reflectors or transponders for radar searches, significantly improved detection ranges. Available information, supplemented by modelling, of acoustic detection systems suggested PIW's and other small targets equipped with lightweight pingers would be

detectable even under severe environmental conditions to ranges of at least 1 km.

To estimate the usefulness of the various sensors in a small target detection role, the available information on their performance was used in a comparison with visual search sweep widths under average and severe east coast conditions. The visual sweep widths were computed in accordance with the tables given in the Canadian Coast Guard Search and Rescue Manual (Recognising that recent USCG tests suggest these tables are simplistic, and that a number of factors in addition to visibility, target size, wave height and cloud cover should be taken into account.). Calculated visual sweep widths for the 15 m and the 7 m boats, the liferaft and the PIWs under average summer and winter east coast environmental conditions are approximately 8 km, 4 km, 2 km and 0.3 km, respectively. Under severe summer conditions, fog over the Scotian Shelf and the Grand Banks will reduce average visual sweep widths to 1 km or less. Elsewhere, higher sea states are the dominant factor, and visual sweep widths are reduced approximately 25 percent.

Computed sweep widths for detection of a small boat or liferaft equipped with a radar reflector for the radar aboard the larger vessel used in the USCG tests are 6.3 km, 2.4 km and 0.6 km assuming a 50 percent probability of detection and sea states 3, 4, and 5, respectively. Although these are less than the corresponding visual values, they are independent of light conditions and the presence of fog or light rain. Without the radar reflector, it appears these targets will not be detectable above sea state 2. There is insufficient information to compute sweep widths for the FLIR and LLLTV, but detection ranges indicate they would be in the range of 1 to 4 km under sea states less than 2 and good visibility (no fog or precipitation)

conditions for targets without detection aids. These are less than the equivalent visual sweep widths so their application would generally be restricted to periods of darkness. Active acoustic systems (i.e., with the target carrying a pinger) are believed to have promise for ranges of 2 to 4 km under virtually any environmental conditions.

Given the paucity of data on which to base sweep width calculations under Canadian east coast conditions, an experimental target detection program based on the USCG methodology has been proposed for Placentia Bay on the south coast of Newfoundland. The targets should include a covered fibreglass lifeboat, an escape capsule, a high speed rescue craft, a canopied liferaft and a simulated PIW - all of which are possible targets in search and rescue operations of the east coast. The program should include visual and radar search, and should be carried out during the day and night. The targets should be with and without detection aids such as lights, heat packs, and radar reflectors. The objectives would be to extend the existing USCG dataset for sweep width calculations from sea state 2 to 3 or 4, and to verify radar performance modelling results for the same sea states. Some of the targets should be equipped with pingers to test an acoustic detection system, and FLIR and LLLTV systems should be included if available and if they do not detract from the primary visual and radar search objectives of the tests.

SOMMAIRE

L'objet de la recherche a été l'évaluation des techniques connues de télédétection appliquées aux cibles de petites dimensions (C.P.D.) flottant à la surface de la mer. Deux études ont été financées parallèlement par le Centre de développement des transports: la première menée par Bercha and Associates à Saint-Jean, Terre-Neuve, sur les systèmes, aéroportés; la deuxième, objet du présent rapport, conduite par NORDCO, également de Saint-Jean, sur les systèmes embarqués.

Les C.P.D. sont definies comme ayant une longueur totale inférieure à 20 m et englobent les embarcations, les bouées, le matériel océanographique, les personnes à la mer (P.A.M.) et les épaves de toutes sortes. Des facteurs divers tels que forme, dimension, couleur, matériau et aides à la télédétection éventuellement transportées par les cibles ont été pris en compte. Pour analyser les performances des capteurs considérés, quatre cibles distinctes ont été caracterisees: des embarcations de 15 et de 7 m, un bateau pneumatique de sauvetage et une P.A.M. En outre, les chercheurs ont caractérisé les conditions climatiques moyennes (probabilité de dépassement de 50 p. 100) et difficiles (probabilité de 25 p. 100), à l'égard de secteurs géo-climatiques représentatifs du golfe du St-Laurent, de deux secteurs de la plate-forme Scotian, deux de la région des Grands bancs, un au large du Labrador et un, enfin, au large de l'île de Baffin. Les conditions climatiques moyennes correspondent généralement à des états de mer 2 ou 3 l'été et 4 ou 5 l'hiver. Les conditions difficiles correspondent à des états de mer 4 l'été et 5 ou 6 l'hiver, et il convient de rappeler que les glaces constituent un facteur supplémentaire à prendre en compte dans les secteurs septentrionaux durant les mois d'hiver et de printemps.

Les systèmes ayant fait l'objet de la présente recherche ont été: le capteur IR à balayage frontal, la télévision à faible niveau de luminosité, les radars de marine dans les bandes X et S et le sonar. Le principe fondamental de chacun des systèmes est expliqué et les facteurs susceptibles de dégrader les performances, tels que les mouvements du navire, ont été abordés. Quant à l'information sur l'aptitude de ces systèmes à détecter les objets visés, elle a été puisée à diverses sources: publications, notices des fabricants, interviews personnelles, notamment avec les opérateurs et, enfin, modélisation mathématique.

Le rapport montre que le capteur IR à balayage frontal non stabilisé a d'aussi bonnes performances de jour que de nuit et que celles-ci sont intéressantes à un état de mer inférieur à 3. La portée utile de ce capteur a été de 3 à 5 km dans le cas d'une cible de 10 m. Mais ses performances se dégradent en cas de précipitation et de brouillard. La télévision à faible niveau de luminosité de type actif donne de meilleurs résultats que le type passif, mais les performances dans les deux cas se dégradent en présence de fortes luminosités, de pluie et de brouillard. Les radars de marine de type courant ont donné, au cours de la campagne intensive d'expérimentations menée par la Garde côtière des Etats-Unis, des résultats aussi bons sinon meilleurs que la détection visuelle, dans le cas de petites embarcations de d'états de mer jusqu'à 2, mais ils sont moins efficaces pour détecter une cible de très petite dimension, une P.A.M., par exemple. Dans les conditions propres aux expérimentations de la Garde côtière américaine (états de mer entre 0 et 2), les radars de marine peuvent constituer un moyen de détection efficace, dans l'obscurité, par pluie légère et dans le brouillard. Par la modélisation mathématique, on s'est aperçu que les performances des radars de marine

courants qui se dégradent rapidement lorsque l'état de mer dépasse le niveau 3 pouvaient être améliorées par un traitement de signal approprié. Leur portée réelle s'améliorait considérablement aussi lorsque la ou les cibles étaient équipées d'une aide telle que source de lumière, matériau réfléchissant dans le cas d'une détection visuelle, réflecteurs radar ou transpondeurs dans le cas d'une détection au radar. Quant aux systèmes sonar, l'information disponible, complétée par des études de modélisation, laisse croire qu'une C.P.D. ou une P.A.M. équipée d'un générateur d'impulsions (balise acoustique de détresse) de faible poids pourrait être détectée à une distance d'au moins 1 km, dans les conditions climatiques les plus difficiles.

Afin de pouvoir évaluer l'aptitude des divers systèmes à détecter des C.P.D., une comparaison a été faite entre les systèmes de détection radar et la détection visuelle, sur le plan de la largeur des couloirs balayés dans les conditions climatiques précédemment définies. Dans le cas de la détection visuelle, ces largeurs avaient été calculées à partir des tables fournies par la Garde côtière canadienne dans son manuel sur la recherche et le sauvetage (il est à noter que ces tables, au vu des récentes expérimentations faites aux États-Unis, seraient très simplistes et qu'il y aurait lieu qu'elles prennent en compte un certain nombre de facteurs autres que la visibilité, les dimensions, la hauteur des vagues et la nébulosité). Pour ce qui est des embarcations de 15 et de 7 m, le bateau de sauvetage et les P.A.M. dans les conditions climatiques moyennes d'été et d'hiver, les largeurs calculées sont d'environ 8, 4,2 et 0,3 km, respectivement. Mais ces largeurs peuvent tomber à 1 km ou moins en été lorsque les conditions sont très difficiles, par exemple lorsque le brouillard recouvre la plate-forme Scotian et les Grands bancs. Ailleurs, ce sera l'état de mer qui dominera et là aussi les largeurs se trouveront réduites de quelque 25 p. 100.

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En ce qui concerne la détection d'une petite embarcation ou d'un bateau de sauvetage, équipés d'un réflecteur radar compatible avec les radars à bord des navires utilisés par la Garde côtière américaine dans ses essais, les largeurs calculées correspondantes sont de 6,3, 2,4 et 0,6 km avec une probabilité de détection de 50 p. 100, lorsque les états de mer sont de niveau 3, 4 et 5, respectivement. Bien qu'inferieures aux valeurs correspondantes obtenues en détection visuelle, elles demeurent insensibles à la luminosité, au brouillard et à la pluie légère. Sans le réflecteur, ces cibles ne pourront probablement pas être détectées par état de mer de 2 ou plus. Concernant le capteur IR à balayage frontal et le système de télévision, l'information disponible est trop pauvre pour permettre le calcul de ces largeurs, mais d'après les portées utiles constatées, elles seraient de l'ordre de 1 à 4 km par état de mer inférieur à 2 et par bonne visibilité (ni précipitation ni brouillard), dans le cas d'une cible sans réflecteur. Ces valeurs sont inférieures aux largeurs équivalentes en détection visuelle, de sorte que ces systèmes trouveront leur application principale dans l'obscurité. Les systèmes acoustiques actifs (c.-à-d. avec générateur d'impulsions) promettent des largeurs de 2 à 4 km dans presque toutes les conditions climatiques imaginables.

Vu la pénurie d'information susceptible de permettre le calcul des largeurs de couloir dans les conditions climatiques de la côte Est de Canada, un programme expérimental fondé sur la méthodologie de la Garde côtière américaine a été proposé pour la détection de C.P.D. dans la baie Placentia, au sud de Terre-Neuve. Les cibles seraient un canot de sauvetage en fibres de verre, une capsule de sauvetage, une vedette de sauvetage rapide, un radeau de sauvetage avec tente et une P.A.M. simulée, autant de cibles qui pourraient un jour ou l'autre faire l'objet d'une

opération de recherche et de sauvetage authentique, au large de la côte Est. Ce programme de recherche devrait porter sur la détection visuelle et la détection radar, tant de jour que de nuit, les cibles étant équipées ou non d'aides à la détection: sources de lumière, générateurs d'énergie thermique et réflecteurs radar. L'objectif de ce programme serait double: élargir la base de données rassemblée par la Garde côtière américaine de manière à étendre le calcul des largeurs à l'état de mer 3 ou 4 au lieu de 2 et vérifier les prévisions théoriques obtenues par modélisation concernant les performances des radars dans les mêmes conditions (états de mer). Il faudrait équiper certaines cibles de générateurs d'impulsions afin de vérifier les performances du système acoustique. Il faudra si possible vérifier aussi les performances du capteur IR à balayage frontal ainsi que la télévision à faible niveau de luminosité, dans la mesure où cela n'empêchera pas de réaliser les principaux objectifs de la recherche en matière de détection visuelle et radar.

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1.0 INTRODUCTION

The objective of this project has been to assess currently available remote sensing techniques for the detection of small objects on the surface of the ocean. The results are of direct relevance to the Federal Government's search and rescue mandate and to the conduct of general marine operations in ice frequented waters around Canada. Two parallel studies were commissioned by the Transportation Development Centre (TDC): one by F.G. Bercha and Associates of St. John's to evaluate airborne sensor systems, and a second, which is reported in this document, by NORDCO Limited of St. John's to evaluate the effectiveness of shipboard remote sensing systems. Two review meetings attended by representatives of the Canadian Coast Guard (CCG), TDC and the two contractors, were held in the course of the work: the first to obtain agreement between the contractors and TDC on the nature of the targets of interest and the environmental conditions relevant to the study; and the second to review the conclusions and recommendations arising from the studies prior to preparation of the final reports.

At the first meeting vessels of different types, sizes and structural materials were identified, together with detection aids they might be carrying. The various types of buoys encountered at sea (navigation, oceanographic and fisheries) and the range of clothing or survival equipment a man in the sea might be wearing were also identified. The nature of debris that might be associated with an accident was discussed - both from a ship and from an aircraft. The question of false alarms (wildlife or ice on the sea surface, general debris, and vessels involved in normal

operations) was raised and it was recognized that there could not be any hard and fast rule as to what would constitute a false alarm under a search and rescue situation due to the range of possible scenarios. The targets utilized in the study are discussed in Section 2 of this report.

Environmental conditions off the east coast under which the sensors might be expected to operate include extremes of air and sea temperatures, fog, rain, snow and the resulting visibility conditions, daylight versus night conditions, extremes of wind and wave conditions, and the seasonal presence of sea ice and icebergs in varying concentrations. Some of these factors may be only of indirect significance to the assessment of target detection systems. For instance, air and sea temperature may only be useful to the search co-ordinator in predicting the likelihood of fog in the area of concern, or the necessity for speed in the search operation when it is suspected men will be in the water at the site of the incident. However, these same parameters may be important in assessing the probability of detection of a given target using an infrared system, or the effects of evaporative ducts on radar performance in the area. Priority areas for environmental information were identified as the Gulf of St. Lawrence, Offshore Scotian Shelf and the Grand Banks. The basis for determining environmental conditions in each area is outlined in Section 3, and the full data set is included in Appendix A.

In NORDCO's original proposal a number of remote sensing systems were identified: low light level television, infrared imagers, microwave sensors and acoustic systems and radio beacons. In Section 4, the operating principles for instruments, with the exception of radio beacons, in each category are described, together with a review of their

effectiveness in the detection of small objects at sea. All sensors could not be treated equally due to the dearth of quantitative information available. In such cases, interviews with manufacturers and with people familiar with the operation of the equipment have been used to estimate sensor performance.

Section 5 deals with the calculation of sweep widths for the different categories of sensor. Visual detection sweep widths for various targets have been calculated from the Search and Rescue (SAR) Manual tables for average and extreme east coast environmental conditions. There is discussion of the validity of these values in the light of recent United States Coast Guard (USCG) experimental results. However, they have been used as a base line against which to compare the effectiveness of remote sensing techniques.

From the review of available information on remote sensing of small targets at sea it is evident that there is little or no knowledge of sensor performance under typical Canadian offshore conditions. Even the USCG visual detection experiments do not encompass typical winter conditions off the Canadian coastline. Therefore, in Section 6, a program of experiments is recommended for the winter of 1985-86. The primary objectives of the experiments would be to establish visual and conventional marine radar sweep widths for Canadian inshore winter conditions. Secondary objectives would be to evaluate infrared and LLLTV systems, which manufacturers may offer on a trial basis, and to determine the effectiveness of acoustic target location systems.

Conclusions and recommendations arising from the study area are summarized in Section 7.

2.0 TARGETS

2.1 Range of Possible Targets

As agreed at the first review meeting, the study is concerned with the detection of small, generally less than 20 metre (m) length overall, objects on the sea surface. Table 2.1 summarizes the information on vessels, buoys and other floating equipment obtained from manufacturers specifications. The key parameters for visual detection are the above water cross section, shape and colour, and for radar detection shape, cross section and construction material. It is clear that targets over 5 m in length are generally "boat" shaped, the exception being escape capsules in the 5 to 10 m diameter range with circular water planes. Construction materials are generally steel for the larger, commercial vessels, and wood or glass reinforced plastic (GRP) for the smaller vessels. Emergency use vessels are generally orange for easier visual detection, but other vessels may be any colour. Floating objects less than 5 m long at the waterline include rubber liferafts, buoys made of steel or GRP with circular water planes and a variety of above water shapes, persons in the water (PIW's) wearing normal clothing, lifevests or survival suits, and debris that may be any shape, size or material. Finally, there are natural targets such as sea ice or icebergs during the winter and spring seasons, and marine wildlife year round.

It is evident from Table 2.1 that many potential targets will have passive or active detection aids. For instance, the larger vessels may carry navigation lights, radar reflectors and emergency equipment such as flares, rockets, and emergency position indicating radio beacons (EPIRB's).

OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
VESSELS										
-Rigid										
-Longliners	4.8 m	1.0 m	13.7 m	4.5 m	Boat	Wood,GRP, & Steel	Various Colours	Radar Reflect-ors	-Horn, Light(NAV) -Flares, Rockets -EPIRB's -Radio	Free Board Is Excluding Masts -There is About 1200 Vessels Operating In Nfld Up To 50 Miles From Shore
	2.6 m	3.0 m	19.8 m	6.4 m	Boat	"				
-Pleasure Craft	2.0 m	0.9 m	9.8 m	3.4 m	Boat		Various Colours	-	-Nav Light, -Flares -Radio	
	2.5 m	1.2 m	16.0 m	5.2 m	Boat					
-Life Capsules	1.7 m	0.7 m	3.4 m Diam	-	Circle	GRP	Mostly Inter-national Orange	-Some Have Radar Reflect-ors	-Radio's, Lights	
	1.9 m	1.1 m	8.5 m	3.0 m	Ellipse	"	"	-Retro Reflect-ive tape Ref to Coast Guard Drawing ≥ 50 mm x 300mm	-Coast Guard List of Emergency Items	
-Open Boats										
-Fishing	0.6 m	0.4 m	4.8 m	1.4 m	Boat	Wood,GRP, & Aluminium	Various Colours		-May Have Radio & Flares	-These Boats Operate Up To 5 Miles From Shore
	0.9 m	0.9 m	9.1 m	3.5 m	"	"				

Table 2.1 - Description of Targets Expected to be Encountered.

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OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
-Lifeboat	0.4 m 0.8 m	0.4 m 0.8 m	4.3 m 12.0 m	1.6 m 4.3 m	Boat "	Wood & GRP "	Mostly Orange	-Same As Above But No Radar Reflect-ors	-Radio -Coast Guard List of Emergency Items	
-Inflatable -Rigid Rescue Craft	1.0 m	0.7 m	6.7 m	2.6 m	Boat	GRP, Rubber & Aluminium	Orange & Black	"	-Radio & Lights	
	2.0 m	0.9 m	8.5 m	2.9 m	"	"				
-Rescue Craft	0.7 m	0.4 m	5.0 m	1.9 m	Boat	Rubber	Orange & Black	"	"	
-Liferaft 6 to 25 Man	0.9 m	0.3 m	2.1 m Diam	-	Round	Rubber	Most Shells Are Orange	"	-Radio & Light -Coast Guard List of Emergency Items	
	1.3 m	0.4 m	4.1 m Diam	-	"	"				
BUOYS										
-Navigational -Syledis	~1.5-2.0 m	~1.5-2.0 m	2.0 m Diam	-	Cone	Steel	Red		Flashing Light	
-Environmental -Wave Rider	0.45 m	0.45 m	0.9 m Diam	-	Sphere	Steel	Yellow or Orange &	-	Flashing Strobe	Flashes3-4 Times Per 20 Sec Period
	0.6 m	0.6 m	1.2 m Diam	-	"	"	Yellow Verti-cal Strips	-		
-Hermes	0.5 m	0.5 m	1.0 m Diam	-	Sphere	Fiberglass/ Aluminium	Yellow or Orange	-	-	-No Marker, half are set A Drift
	0.6 m	1.5 m	0.7 m Diam	-	Conical Up/Down					- ~12 Deployed Off The East Coast
-Marker (Shipping Aids)	4.5 m	4.5 m	2.9 m Diam	-		Steel	Various Red, Green, Yellow, Orange and White	-Radar Reflector	Flashing Lights Red, Green & Yellow	About 430 Buoys Around Nfld
			1.4 m Diam			Steel		"		

Table 2.1 (con't.)

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OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
-Fishing Buoys and Markers	0.5-0.6 m 10 m	0.4-0.5 m 10 m	Generally 1.0 m Diam 20cm Diam	-	Sphere	Vinal Plastic	Orange	-	-	Some May Have Radar Reflectors Mounted on Top of a Pole (Aluminium)
-Anchor Buoys	~0.5-1 m	~0.5-1 m	~2 to 3 m	~1 to 1.5m	Tube	Steel	Various	-	-	No Marker or Lights
OTHER										
Oceanographic Equipment										
-Streamers	-	Usually below the surface	up to 2km	15cm diam		Plastic & wire steel connectors	mostly clear	filled with varsol oil	-	-Surface buoy with radar reflector & strobe light -Kept afloat by tail buoy with radar reflector & strobe
-Acoustic releases	-	"	0.9m-1.8m	20.0-30cm diam.	Tubular	Steel	Various	-	Acoustic pinger to control and locate unit	-Surface buoy -usually moored used to hold other equipment in place
-Current Meter	-	"	0.6-0.9m	15.0-20.0 cm diam.	"		"	-	-	-Surface buoy -usually moored
Objects on the ocean floor	-	-	Varied	-	Varied	Varied	-	-	-	-This could be debris or complete objects -Ex Anchors, parts of wreckage, etc.

Table 2.1 (con't.)

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OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
PERSONS IN WATER										
-Exposure Suits	0.3 m		2.0 m	60-70cm	Tubular 45°	Neoprene Foam	Orange	-Retro reflective tape on hood & upper arms	-Whistle -Automatic light -Saltwater activated -360° visibility -1-2 mile range -2 week battery life	
-Floaters	0.3 m		2.0 m	60-70 m	Straight up & down	Ultra soft buoyant foam	Orange	-Retro reflective tape on hood & shoulders	-	
-Lifevests	0.2 m		2.0 m	60-70 m	"	Various buoyant materials cellucose & buoyant foam etc.	Orange	-Retro reflective tape across the top & down the sides, both front & back	-Whistle	
-Heavy Weather Gear	0.1-0.2 m		2.0 m	60-70 m	"	Rubber	Orange/Yellow Black	-	-	
-Normal Gear	0.1-0.2 m		2.0 m	60-70 m	"	Cotton, nylon etc.	Various colours	-	-	

Table 2.1 (con't.)

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OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
DEBRIS										
- Fixed Wing										
Body	2.0-3.0 m	2.0-3.0 m	50-60 m	4.5-6.0m	Tubular	Aluminum	Varied	-	ELT	Craft may be in tact or broken in pieces varing in size & shape.
Wing (each)	0.25 m	0.25 m	15-20 m	3-4 m	Flat	Aluminum	Silver & Varied	-	-	
Tail	3.0-6.0 m	-	12-15 m	2-3 m	Flat	Aluminum	Varied	-	-	
Rotary Wing	1-3 m	1.5-3.5 m	6.0-12 m	2.5-5.0m	Tubular	Aluminum	Varied	-	ELT	Tail section not included
-Debris -Nets & Rope	-	-	-	-	Various	Various Manila, Nylon Polyester, Polypro-pylene	Green, Black, Orange, Yellow, White, and Dark Shades	-	-	
-Garbage Bags	-	-	Various	-	Circular	-Plastic	Various	-	-	
-Wood										
-Logs/Trees	5cm-15 m	-	3.0-9.1 m	-	Tubular	Wood				
-Lumber/Planks	Flush	-	3.0 m	15cm-60cm	Flat	Wood				
-Containers	-	-	6.0x2.5 m x2.5 m	-	Rectangle	Steel Steel & Wood	Various			
			2.5x2.5 x2.5	-	Cube					
-Oil Drums	-	-	1.0 m	0.6 m Diam	Cylinder	Steel	Various	-	-	
-Oil Slick's	-	On The Surface	Various	-	Varied	-				If Within 100 Km of Ice Pack

Table 2.1 (con't.)

OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
FALSE ALARMS -Oil Rigs	25.0-31.8 m	20.0-27.0 m	70.7 m	60.0 m	Rectang-ular	Concrete & Steel	Various	-	-Naviga-tion Lights, -Strobes, Red Light On Top Of Derrick	Freeboard Is Excluding Derrick Add 48.8m -Pontoon Size - L 90m - W 15.2m - D 6.4m -Columns 4 to 8 -9.1m diameter
-Ocean Going Vessels -Work Boat	12-15 m	5.9 m	68.5 m	14.5 m	Boat	Steel	Various	-	Radar Nav Lights, & Standard Coast Guard Required Items	
-Sea Life -Marine Mammal	-	-	1-2 m 10-12 m	50-60 m 2-3 m	- -	- -	Blue/Grey "	- -	- -	-Seals (Herds) -Humpback Whale (School) -Mammal & Tuna Have A Higher Core Temperature Than Than The Water's Temperature
-Sea Birds	-	-	10-20 m	Wind Span 30-40 m			White/Grey			

Table 2.1 (con't.)

OBJECTS	DIMENSIONS				SHAPE	STRUCTURE MATERIALS	COLOURS	EQUIPMENT		REMARKS
	FREEBOARD	DRAFT	LENGTH	BEAM				PASSIVE DEVICES	ACTIVE DEVICES	
FALSE ALARMS (CONT'D)										
-Pack Ice	Counting Ridges 1.5-2 m	6-9 m	30 m Diam	-		Ice				If Within 100 Km of Ice Pack
-Ice Bergs										
-Growler	Varied	Varied	6 m			Ice				200 Tonnes
-Small	"	"	21-60 m			"				7K - 200K Tonnes
-Large	"	"	123-213 m			"				> 2.5 m Tonnes

Table 2.1-(Cont'd)

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In general, emergency vessels and personal floatation systems (for example, lifebuoys) will carry additional detection aids as required by the CCG:

(i) Lifeboats - Class II or III EPIRB's, radar reflector, parachute distress flare, red hand flare, buoyant smoke floats, signalling flashlight, daylight signalling mirror and whistle; and,

(ii) Lifebuoys - self igniting lights and self activated smoke signal.

2.2 Summary

To perform the sensor analysis in Section 4, it has been necessary to reduce the list in Table 2.1 to a few representative targets. These are a 15 m steel boat, a 7 m wood or GRP boat, a round rubber liferaft 3 m in diameter, and a person in the water (PIW). These are summarized in Table 2.2. These targets are both representative of those likely to be encountered off the east coast, and similar to those used by the USCG in an extensive series of SAR related sensor performance tests off the coasts of Florida and New York.

Target	Freeboard	Draft	Length	Beam	Shape	Material	Colour
15 m boat	3 m	1.5 m	15 m	5 m	boat	steel	any
7 m boat	2 m	1 m	7 m	3 m	boat	wood	any
Liferaft	1.2 m	0.3 m	3 m	-	round	rubber	orange
Person in water	0.5 m	1.5 m	0.5 m	0.5 m	vertical cylinder	-	-

Table 2.2 - Targets Used for Sensor Performance Assessment

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3.0 EAST COAST OFFSHORE ENVIRONMENTAL CONDITIONS

3.1 Introduction

To evaluate the various existing surface based sensor systems and methodologies having the potential capability to detect small objects at sea, it was necessary to define the environmental conditions to which these systems are subject over the entire study region. In accordance with the Statement of Work, ranges and typical values of relevant parameters on a monthly or seasonal basis were to be gathered for the entire East Coast of Canada. At the outset of the study, it was proposed to obtain the environmental data for representative regions throughout the study area. Also, at that time, specific environmental parameters to be used in the sensing system assessment were defined by the project manager. These choices were presented and discussed at an initial project review meeting with the Scientific Authority held on February 12, 1985 at the NORDCO Limited offices in St. John's. The selection of representative areas and climatic parameters met with approval, with the addition of freezing sea spray and freezing precipitation. Details of the regions selected, the environmental parameters chosen, and the data base from which they were derived are discussed in the following sections. The complete data set employed in the systems evaluation is given in Appendix A. The data, organized by type and region, is presented mainly in graphic format.

While the results of this study were to be valid for the entire East Coast of Canada, it was also agreed at the initial review meeting that the assessment of sensor system capabilities against an ice background was beyond the scope

of the study. However, for completeness, it was deemed necessary to include climatological data on pack ice and glacial ice in East Coast waters to provide the means to assess the applicability of the present work in regions affected by the seasonal or marginal ice zone.

3.2 Selected Regions

A major portion of the relevant environmental data required for this project, specifically meteorological parameters, sea surface temperatures, and sea state data, are derived from synoptic meteorological observations taken by ships of opportunity transiting East Coast waters. In a recent study (Atmospheric Environment Service, 1984), summary statistics of climatic variables were calculated from all available ship observations for each of the 35 Atmospheric Environment Services (AES) marine forecast areas as defined when the work was carried out. These areas are shown in Figure 3.1. Nine regions have been selected for this present study as being representative of the climate of East Coast waters. These are indicated by the stippled areas in Figure 3.1 and include:

- Georges Bank
- Sable
- Gulf-Magdalen
- Southeastern Grand Banks
- Northern Grand Banks
- Belle Isle Bank
- Northwest Labrador Sea
- Davis Strait

It will be noted that these regions can, in general, be classified as offshore areas. Their selection was, in part, justified since search times in offshore areas are generally

Figure 3.1 - AES East Coast Marine Forecast Areas - 1982
(Atmospheric Environment Service, 1984)

longer than in coastal waters, albeit fewer in number; additionally, with some qualifications, environmental conditions in offshore regions are unlikely to be vastly different from adjacent coastal areas.

3.3 Data Sources

3.3.1 Meteorological, Sea State, Sea Surface Temperature Data

As stated in Section 3.2, summary statistics for climatic variables for each of the selected areas were extracted from Atmospheric Environment Service (1984). The data set from which they were derived consisted of all ship observations available from the 1800's to 1981 and archived on magnetic tape at AES headquarters, Downsview, Ontario. The selected climatic statistics for each area include:

1. Monthly mean air temperature and standard deviation in Celsius degrees;

2. Monthly mean sea surface temperature and standard deviation in Celsius degrees;

3. Percent frequency of visibility less than 5.4, 2.2, 1.1, and 0.5 nautical miles (nmi) for each month of the year;

4. Percent frequency by month of:

   a. light rain, showers and drizzle,
   b. moderate and heavy rain,
   c. light snow,
   d. moderate and heavy snow, and
   e. freezing precipitation (rain and drizzle);

5. Percent exceedence of observed wind speed in knots for each month of the year;

6. Percent exceedence of combined wave height in metres for each month of the year (The combined wave height is determined from the root mean square of the observed wind wave height and the height of the swell waves present).

Although the statistics were calculated from the entire ship observation data base, it is important to note that the observation and coding practice underwent a gradual evolution throughout the period as interest in marine climatology developed. Atmospheric Environment Service (1984) reports:

- Wind, air temperature, and sea surface temperature observations typically began in the 1860's.

- Visibility and present weather observations became reported regularly in the late 1880's.

- Sea (wind) waves were not reported until 1949.

- Swell observations began in 1959.

The data base also shows a very marked increase in marine weather observations beginning in the 1940's due to war time traffic and the subsequent escalation in world trade. Previous to this time there are relatively few data for any of the marine areas. Seasonal variability is also evident in the data with relatively fewer observations reported during the cold season, particularly in areas affected annually by high concentrations of pack ice. In general, the statistics for the northern areas are based on

considerably fewer data and, consequently, are likely to be of lower reliability.

There is evidence of "fair weather bias" in the data as well. This occurs as a result of ship traffic avoiding or moving away from heavy weather conditions or by simply not observing and reporting the weather in storm situations. NORDCO Limited's experience in providing a marine weather forecast service continuously since 1979 primarily in support of exploratory drilling operations on the East Coast is consistent with this conclusion. A fair weather bias will be most evident in the higher wind and sea state statistics for the winter months. It is fair to state that the percent exceedence curves of wind speed and combined wave height determined from the data are, in all probability, lower than reality for the winter months for areas not normally covered by sea ice. A quantitive assessment of fair weather bias in the data base is currently under investigation by AES (Atmospheric Environment Service, 1984).

In addition to the fair weather bias, wave statistics will be affected by observation errors and by coding errors. A relatively common coding error has been to record the wave height as "99" rather than "11" to indicate an undetermined height. This value would be interpretated as an observed wave height of 99 half metres or 49.5 m which is clearly incorrect. The error will affect the extreme tail of the combined wave height percent exceedence curves which appears to approach zero asymptotically.

3.3.2 Sea Spray Ice Accretion

The percent frequency of freezing spray potential for the nine selected marine areas has also been drawn from the

Atmospheric Environment Service (1984). The statistics are based on theoretical icing potential determined from a model developed by Kachurin et al (1974) using inputs of air temperature, wind speed, sea surface temperature, wave height, and salinity. Model outputs are required due to a paucity of actual data on sea spray icing. The representation gives the theoretical icing rate of a cylinder located in the spray zone. Kachurin et al calibrated this output with actual freezing spray icing collected on Russian trawlers. Data on trawler icing off the East Coast published by Stallabrass (1980) was used to apply the model output to Canadian waters (Atmospheric Environment Service, 1984). The derived data on percent frequency of freezing spray potential are given according to the following severity classes:

Light	0 to 3 centimetres (cm) / 24 hours
Moderate	3 to 6 cm / 24 hours
Heavy	6 to 14 cm / 24 hours
Severe	14+ cm / 24 hours

The statistics are intended to be valid for offshore trawlers and other similar sized craft. Actual ice accretion rates are a function of vessel size and type (for example, superstructure arrangement, etc.) and direction and speed of travel relative to wind and seas, in addition to the prevailing environmental factors. The confidence that can be placed on the data is difficult to estimate; it is a function of the limitations of the model and the quality of the input data. For example, the vertical distribution of spray ice accretion is not accounted for in the model. The most serious problem with respect to data quality is expected to affect the statistics in northern waters where the data base is relatively smaller and the presence of pack ice limits wave development, hence, reducing the chances of spray ice accretion.

3.3.3 Typical Underwater Profiles and Ranges of Temperature, Salinity, and Density

To describe the relevant oceanographic conditions in East Coast waters, a series of typical underwater profiles and ranges of temperature, salinity, and density have been drawn from U.S. Naval Oceanographic Office (1967). These summary data are based on oceanographic stations taken on numerous oceanographic cruises for the period 1902 to 1962 using. The typical density (sigma-t) curves were calculated from the temperature and salinity data using the accepted relationship (for example, Neumann and Pierson, 1966). The data are summarized by area and by month for four months of the year. Summary plots are valid for very large areas such as the Grand Banks, Labrador Shelf, and the Northern Gulf of St. Lawrence. The months of February, May, August, and November illustrate the seasonal variation. Thus the range of temperature, salinity, and density that can occur, particularly in the upper layers, is quite wide.

3.3.4 Underwater Sound Speed Profiles in East Coast Waters

The speed of sound at a point in the water column is a function of temperature, salinity, and pressure. Thus data, taken from oceanographic stations have been used to derive sound speed profiles for East Coast waters. These data have been summarized by Scrimger (1979) for various areas off the East Coast for each season of the year. The regions include:

- Scotian Shelf
- Southern Grand Banks
- Northern Grand Banks
- Southern Labrador Shelf and Northeast Newfoundland Shelf

Depending on the area, the oceanographic data set from which these speed summaries were prepared was collected during the period 1928 to 1976.

3.3.5 Median and Extreme Ice Edge Positions 1963-1973

As indicated in Section 3.1, a summary of the seasonal variation of typical (median) and extreme limits of sea ice coverage on the East Coast is included in order to make possible an assessment of the limitations of the sensing system evaluation due to the presence of an ice background. The climatology of the seasonal ice distribution on the East Coast is illustrated using a series of bi-weekly ice charts taken from Markham (1980). The data upon which these were derived was obtained almost entirely from Federally supported ice reconnaissance flights during the eleven year period 1963 through 1973. The area of coverage includes the Gulf of St. Lawrence, Newfoundland waters, and Labrador waters south of Latitude 55^{o}N. On some charts, the median and extreme limits in northern areas are based on only nine or ten years of data. In addition to these boundaries, the number of years that ice was present and the median concentration for each half degree latitude by one degree longitude grid area has been determined.

Despite the relatively short period of data collection upon which the ice charts were prepared, it would appear that they provide a good summary of the climatology of pack ice distribution on the East Coast of Canada.

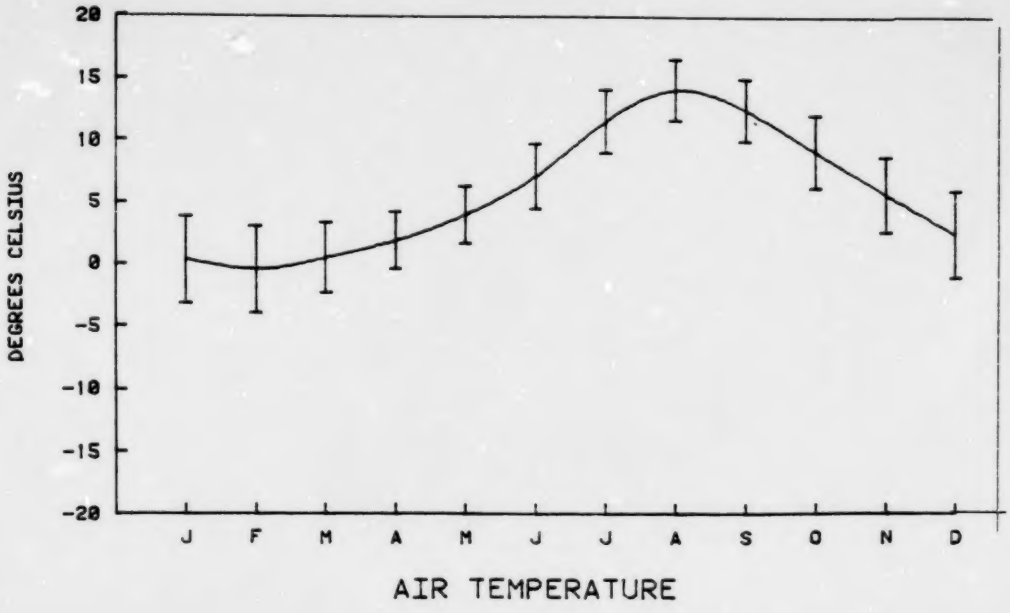
3.3.6 Data on Glacial Ice

The occurrence of glacial ice in the form of icebergs, bergy bits, and growlers must be considered since their

presence represents an increased probability of false alarm occurrence during a search event. The data set upon which summary information and statistics have been developed has, almost entirely, been due to the surveys of the International Ice Patrol (IIP) service operated by the U.S. Coast Guard since 1913. A detailed assessment of this data base is beyond the scope of this study. The primary mandate of the IIP has been to advise international shipping of the most southern and eastern limits of icebergs in the Northwest Atlantic; more specifically, efforts have been concentrated in Newfoundland waters during the spring and early summer months when iceberg concentrations are highest. Several summary charts have been drawn from the literature and are included in Appendix A to illustrate generally the seasonal variation of the distribution of glacial ice in East Coast waters. It is important to note that the IIP data set underestimates the population of small pieces of glacial ice (growlers and bergy-bits) as these are more difficult to observe. A further discussion of glacial ice occurrence is given in Section 3.4.1.

3.4 Data Presentation

To readily assimilate the climatic variables and allow convenient selection of representative values to help in assessing the performance of the various shipborne remote sensing systems under consideration, it was decided to use a variety of graphic presentations. For each of the marine areas examined, plots showing monthly variations of each parameter as listed in Section 3.3.1 were prepared. Figures 3.2 through 3.6 illustrate the climatic statistics for the Northern Grand Banks marine area. These are repeated along with those of the other marine areas in Appendix A. Each graph is self-explanatory.



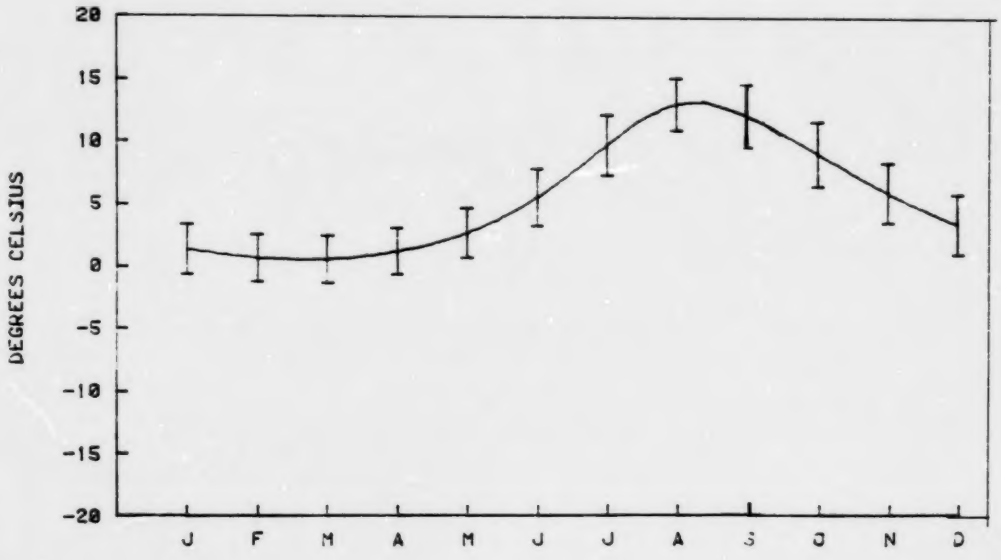


Figure 3.2 - Annual Air and Sea Surface Temperature Conditions for the Northern Grand Banks Marine Forecast Area

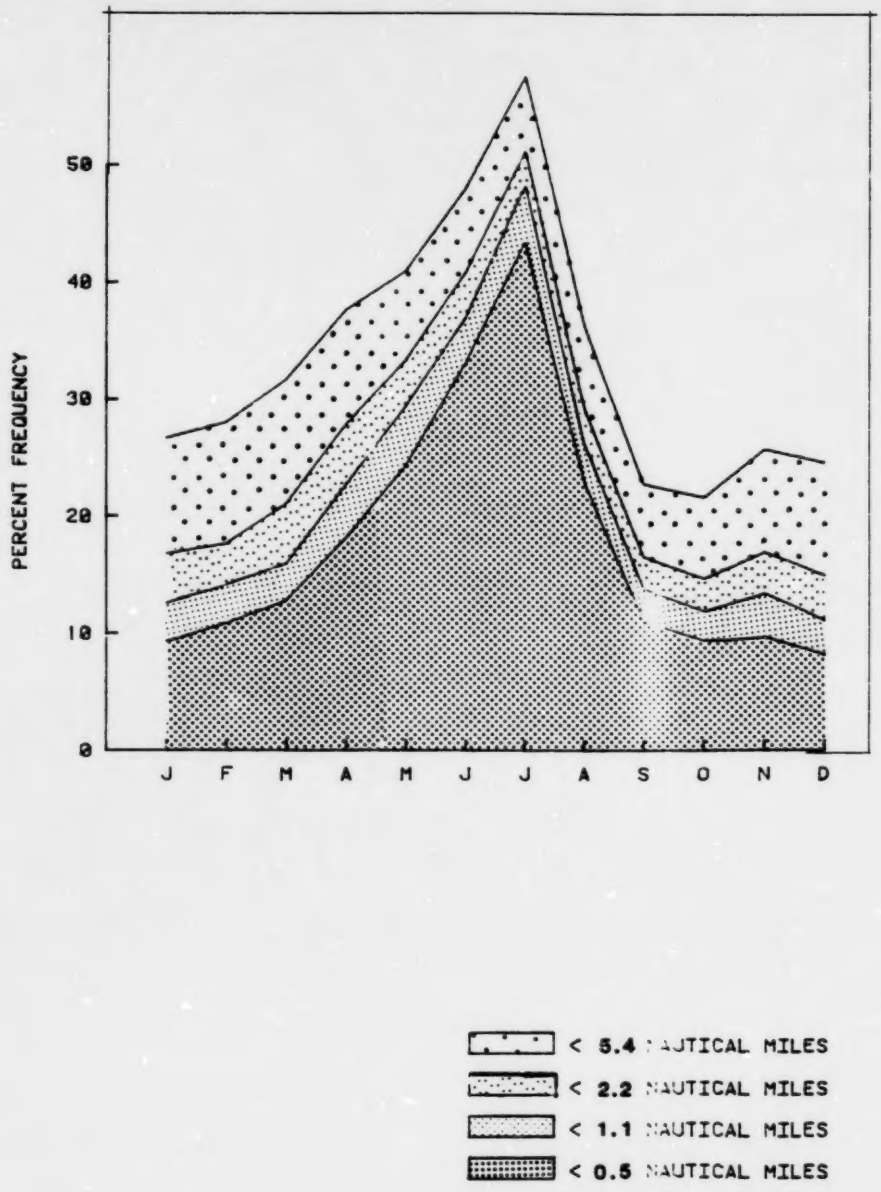


Figure 3.3 - Percent Frequency of Visibility for the Northern Grand Banks Marine Forecast Area

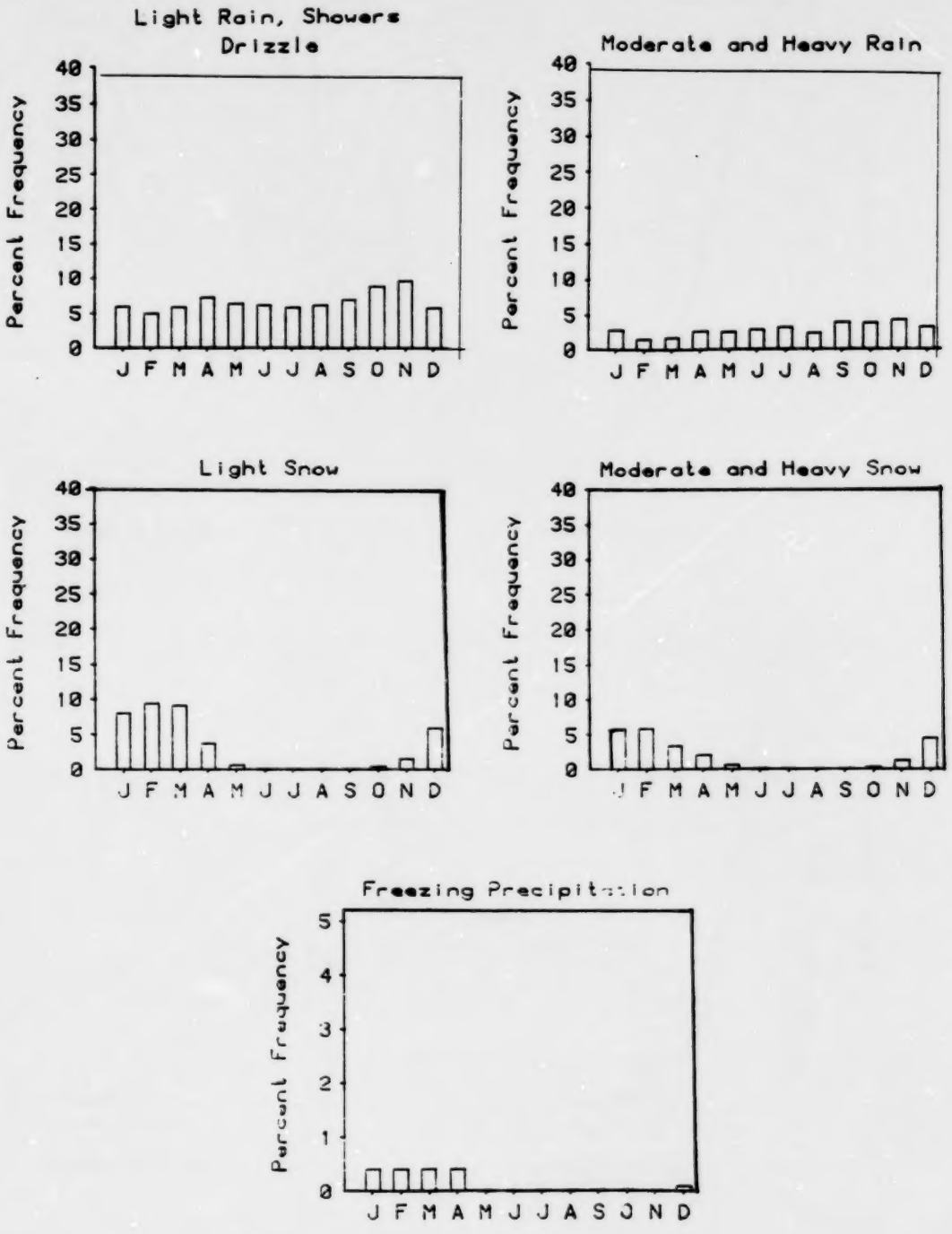


Figure 3.4 - Percent Frequency of Precipitation for the Northern Grand Banks Marine Forecast Area

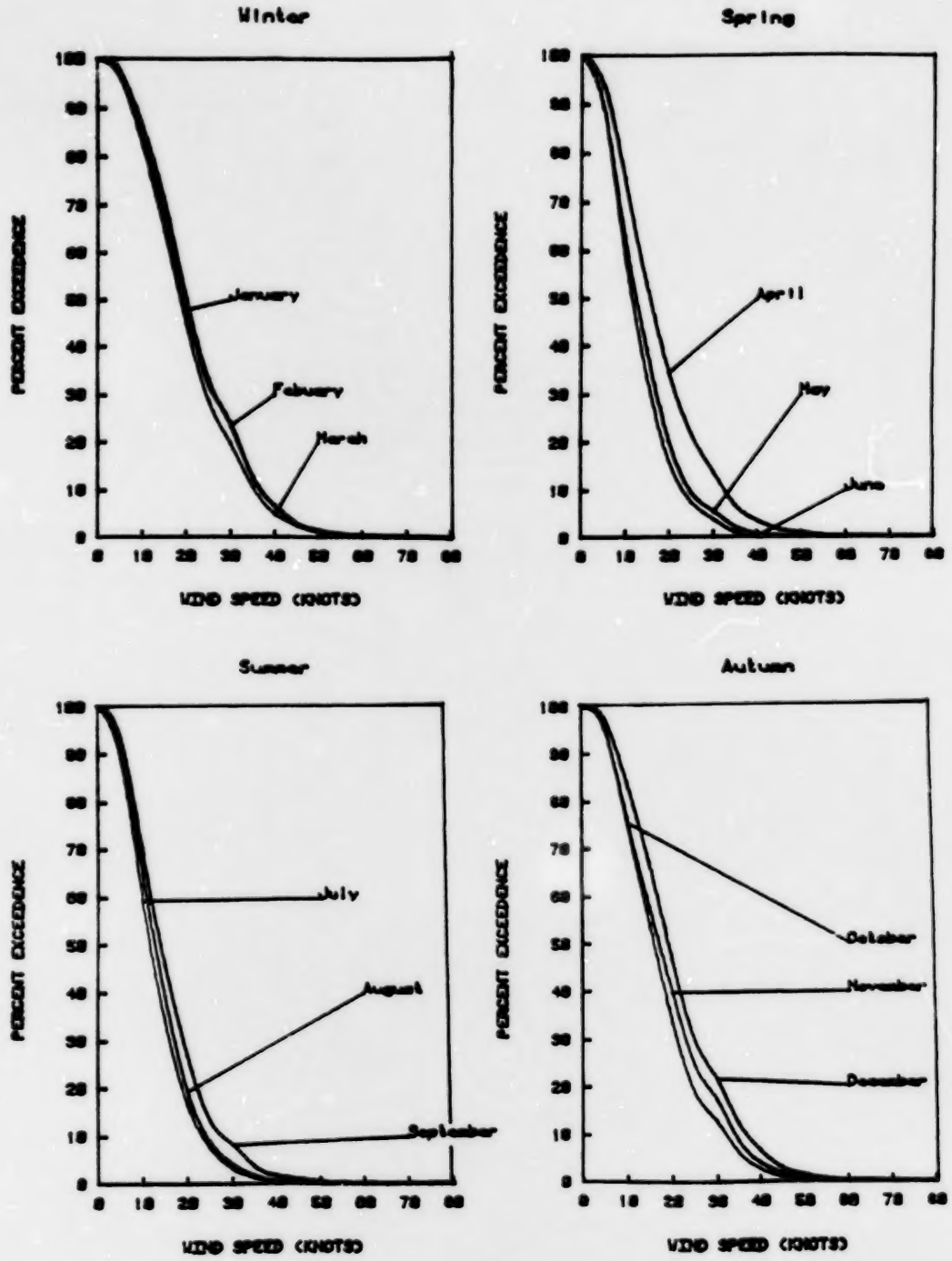


Figure 3.5 - Percent Exceedence of Wind Speed for the Northern Grand Banks Marine Forecast Area

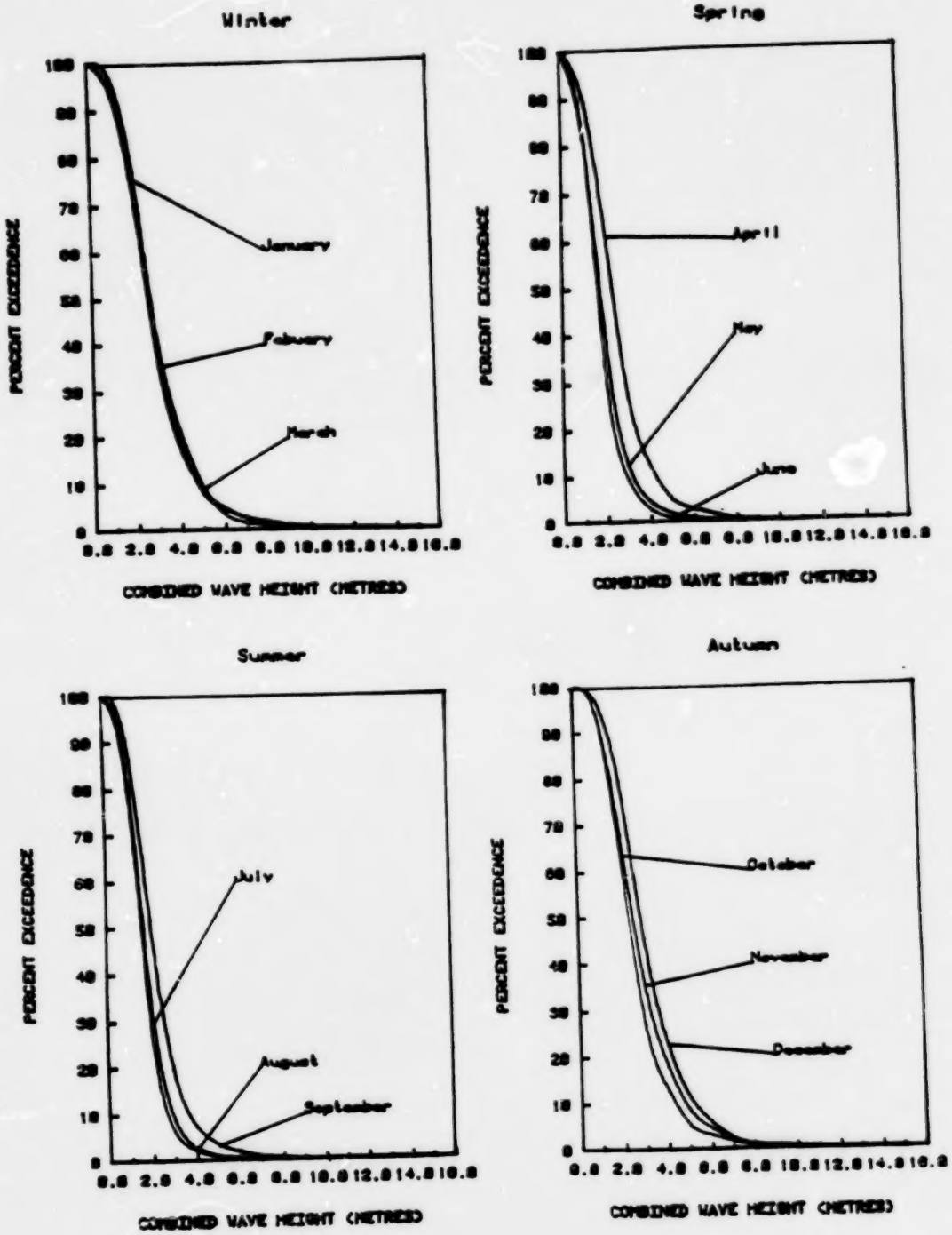


Figure 3.6 - Percent Exceedence of Combined Wave Height for the Northern Grand Banks Marine Forecast Area

SEVERITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
LIGHT	9.5	13.7	5.2	2.2	-	-	-	-	-	-	0.2	5.6
MODERATE	2.3	3.1	0.7	-	-	-	-	-	-	-	0.1	0.9
HEAVY	1.3	2.6	0.1	0.1	-	-	-	-	-	-	-	0.4
SEVERE	-	0.1	-	-	-	-	-	-	-	-	-	-

Table 3.1 - Percent Frequency of Freezing Spray Potential For the Northern Grand Banks

The monthly statistics of freezing spray potential for each area are presented in tabular form giving the percent frequency of each of the severity classes as discussed in Section 3.3.2. An example for the Northern Grand Banks is shown in Table 3.1.

Figure 3.7 shows typical underwater profiles and ranges of temperature, salinity, and density of sea waters for the winter (February). In Appendix A, data for the months of May, August, and November representing the spring, summer, and fall, respectively, are given along with that of February. Figure 3.8 is a plot of the average sound speed profile in water and its deviation for the Northern Grand Banks during the winter season. These profiles, calculated from temperature, salinity and pressure data, are taken from Scrimger (1979).

Figure 3.9 shows a summary ice chart taken from Markham (1980) to illustrate the series of nineteen charts found in Appendix A that depicts the season variation of pack ice distribution on the East Coast of Canada. The legend accompanying the figure provides the necessary interpretation information.

3.4.1 Icebergs, Bergy Bits and Growlers

The general drift of icebergs, bergy bits, and growlers is illustrated in Figure 3.10. In Canadian waters, the highest concentrations occur in northern Baffin Bay. As these pieces of glacial ice drift generally south-southeastward in the Baffin/Labrador Current system, they are subject to gradual deterioration except where protected by the presence of pack ice. In general, the median size of the glacial ice masses decreases southward. Relatively few icebergs are found beyond the schematic drift

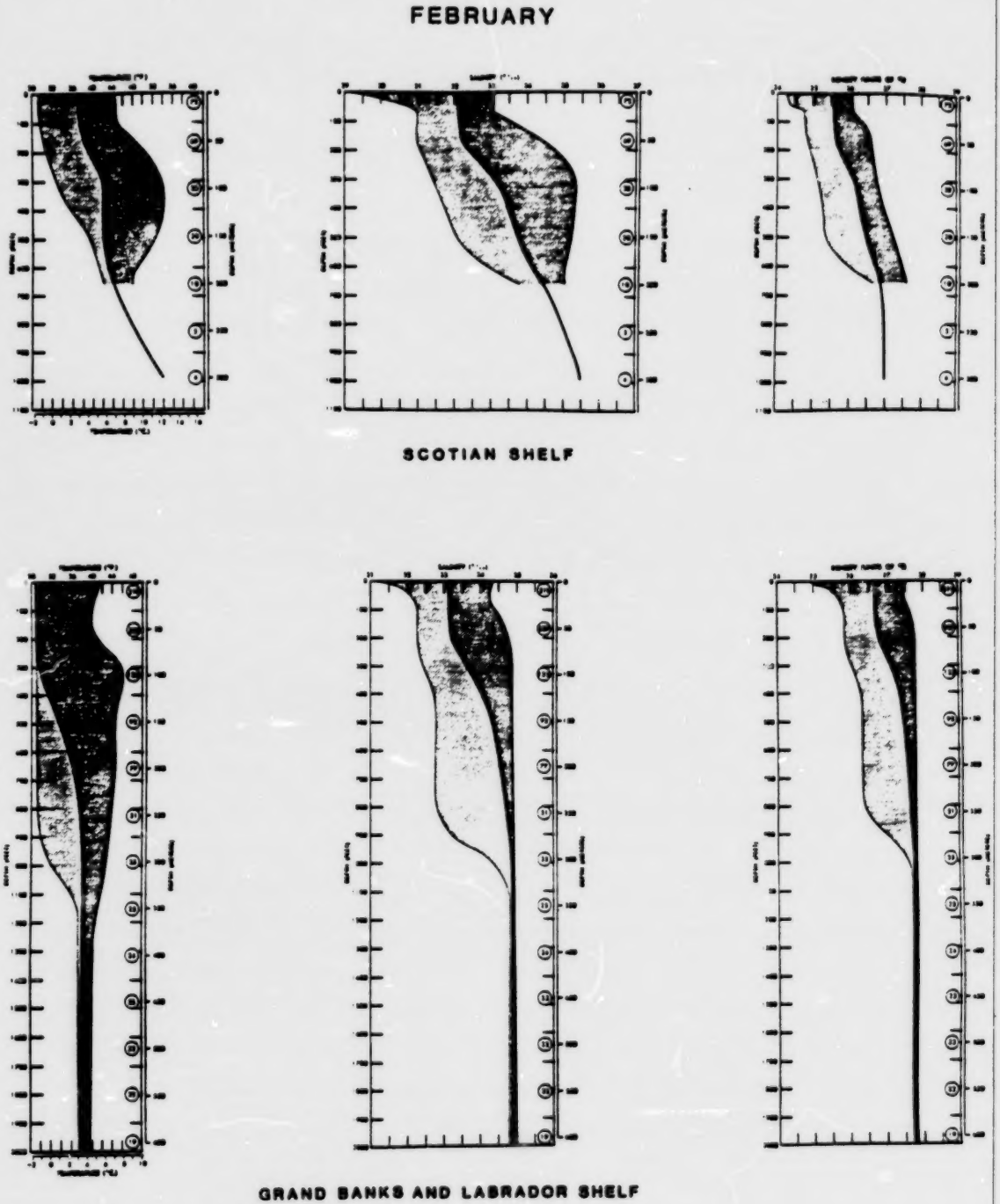


Figure 3.7 - Typical Profiles and Ranges of Temperature, Salinity and Density (U.S. Naval Oceanographic Office, 1967)

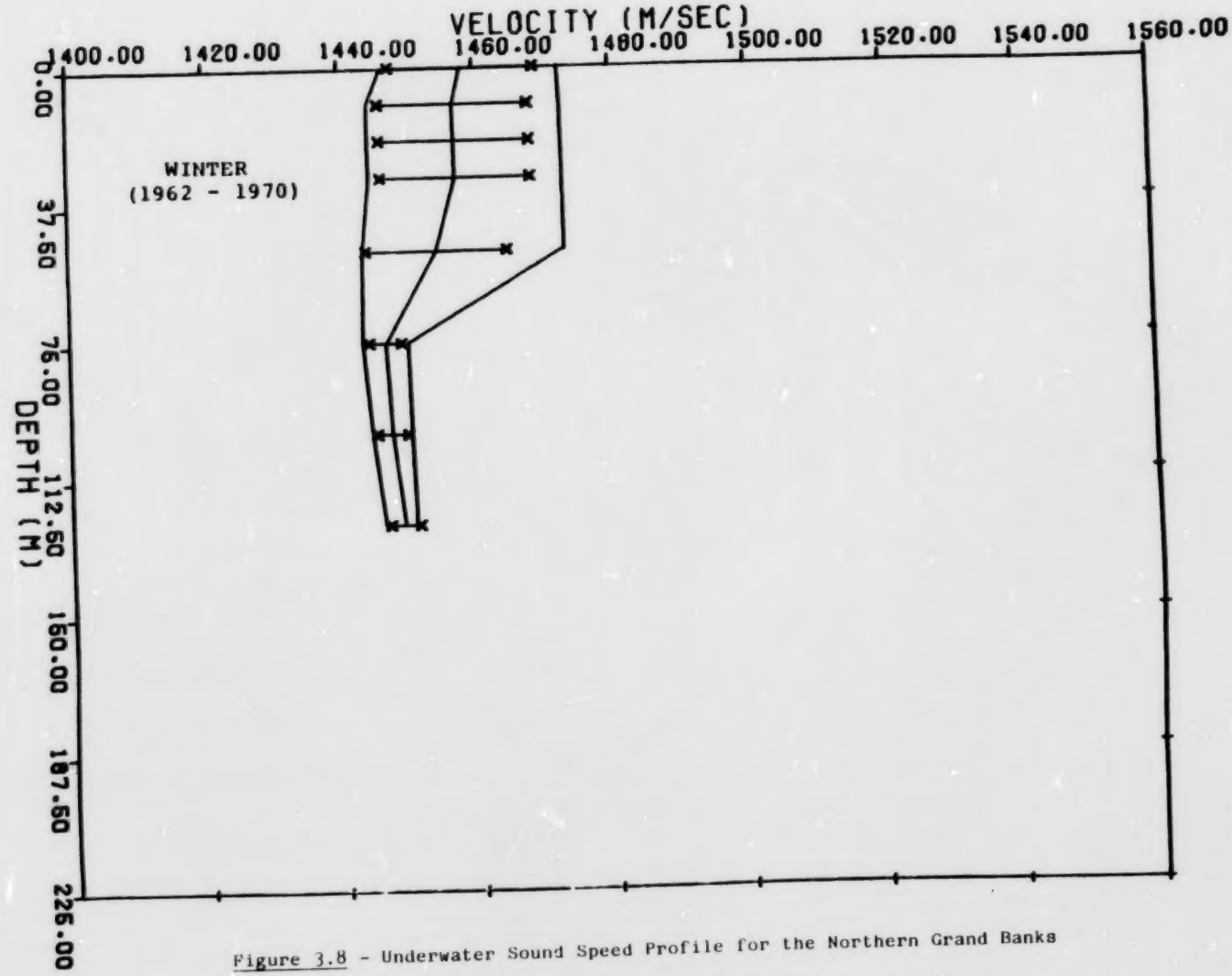


Figure 3.8 - Underwater Sound Speed Profile for the Northern Grand Banks

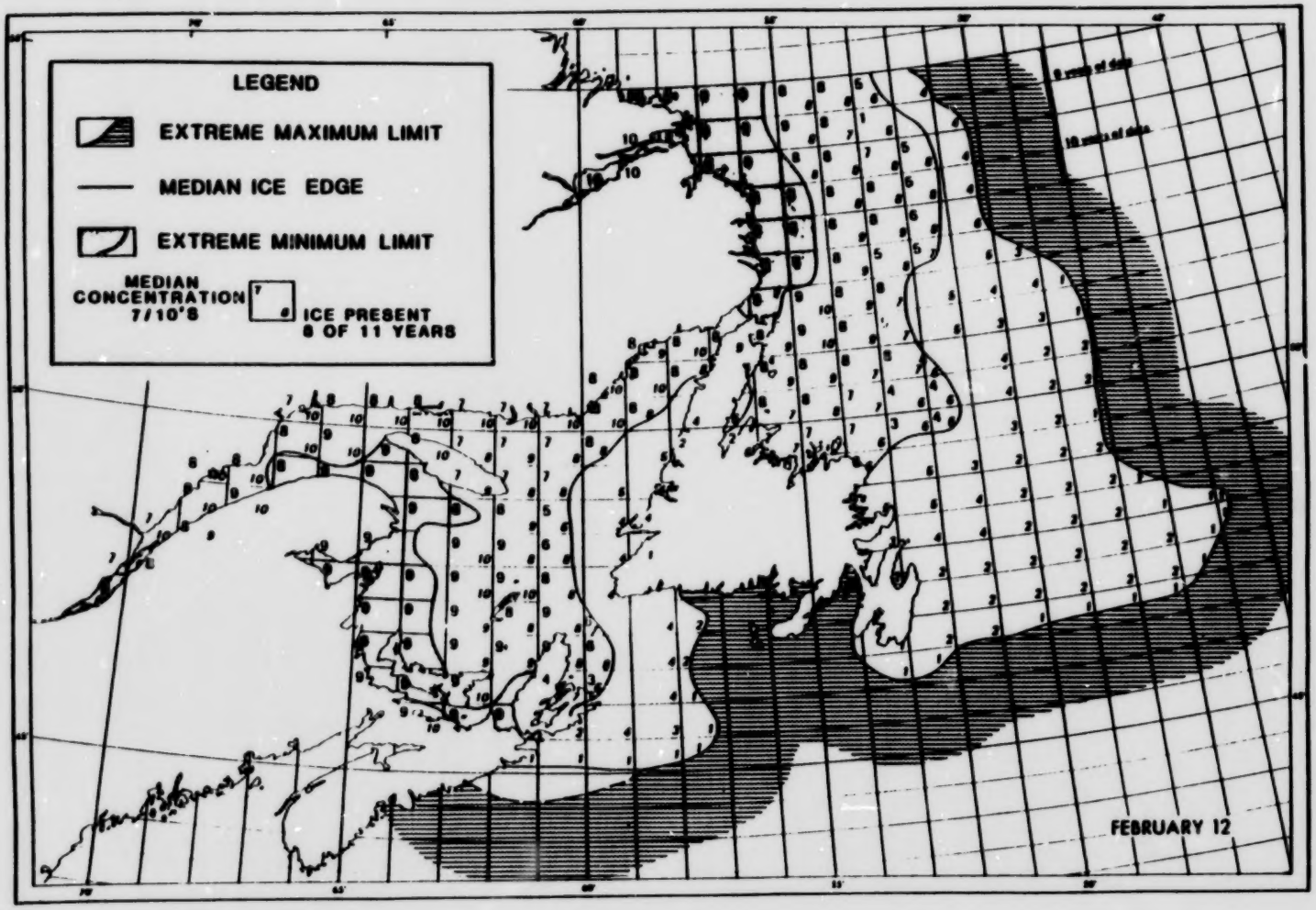


Figure 3.9 - Median and Extreme Ice Edge Positions for 1963-1973 (Markham, 1980)

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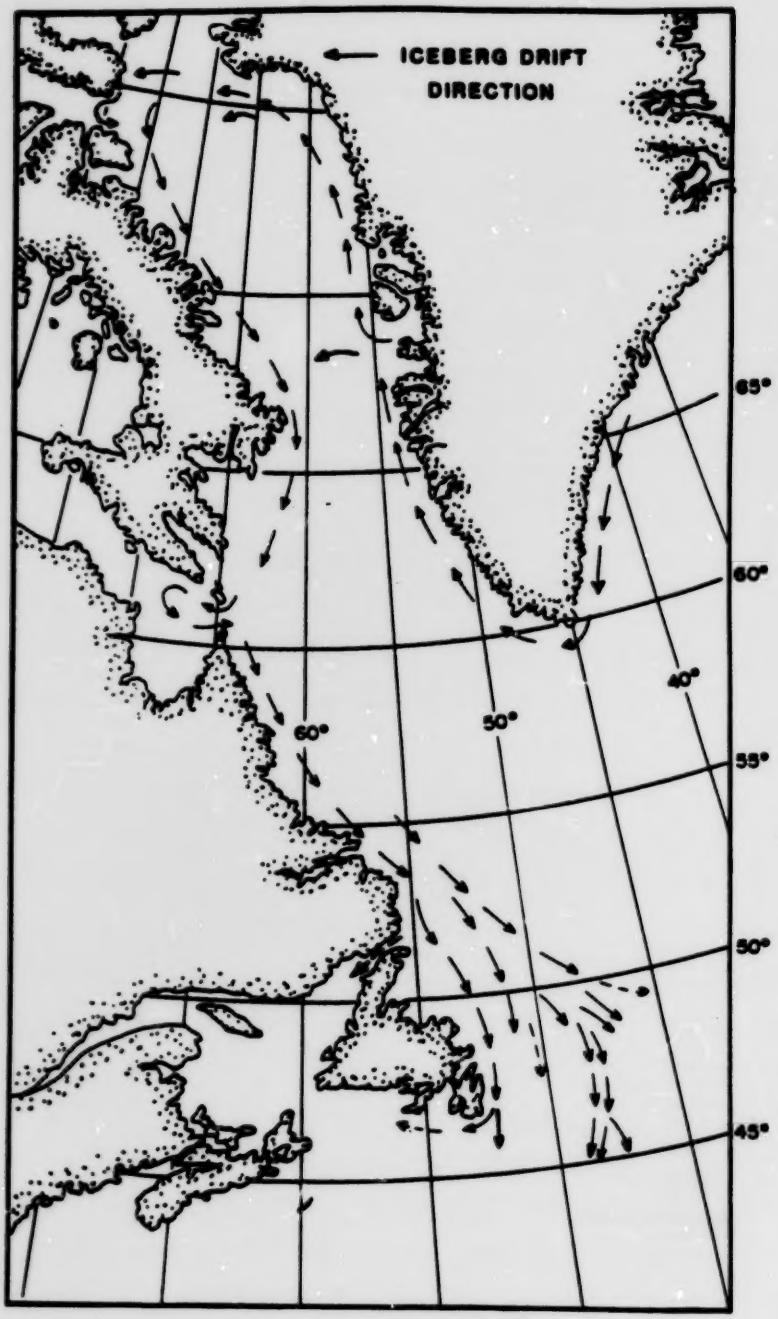

Figure 3.10 - General Direction of Iceberg Drift

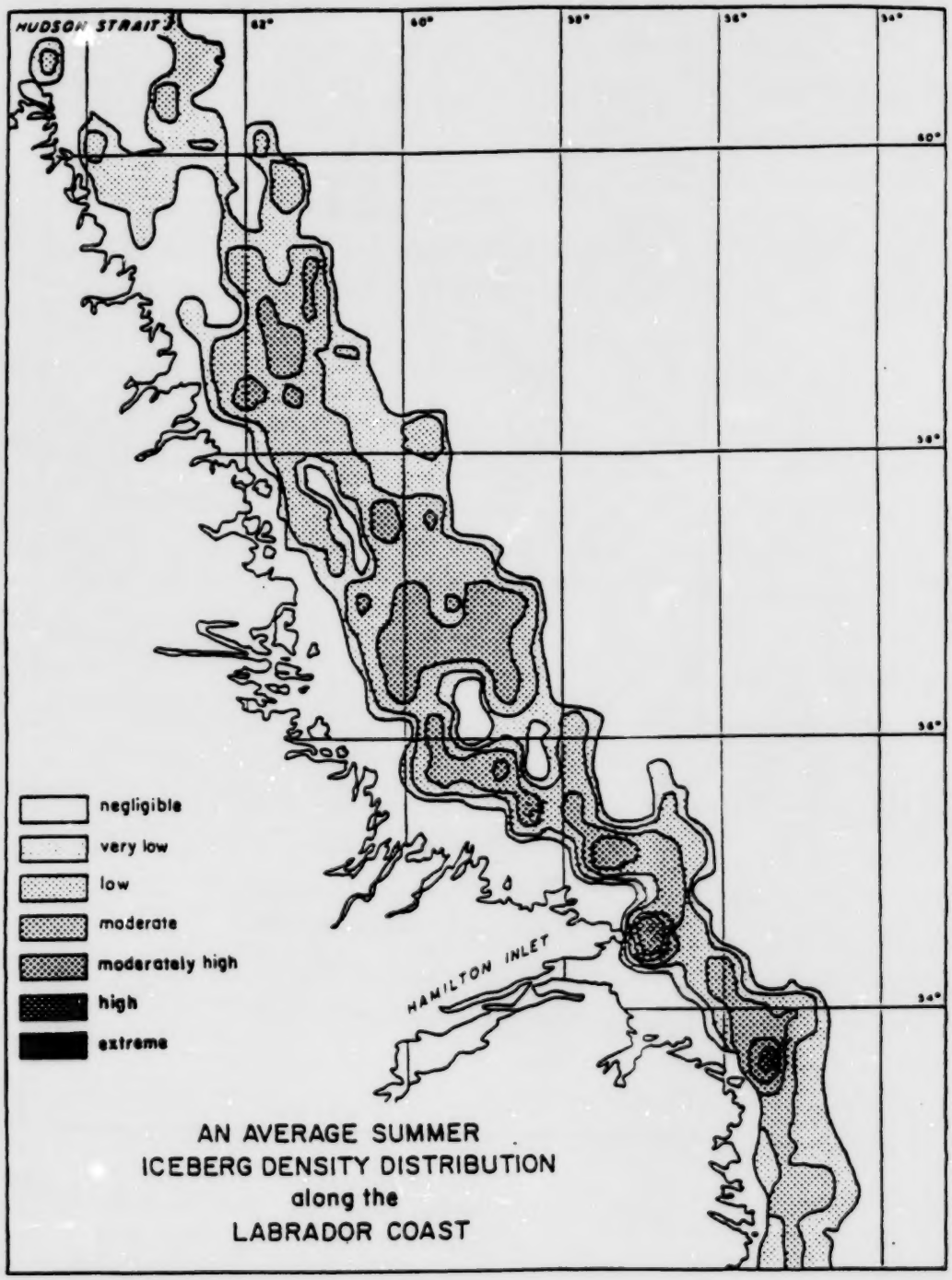

Figure 3.11 - An Average Summer Iceberg Density Distribution Along the Labrador Coast (Gustajtis and Buckley, 1977)

arrows shown in the figure. A few diagrams have been collected in Appendix A to illustrate the mean iceberg density during the various seasons. As an illustration, Figure 3.11 shows the iceberg density along the Labrador Coast during the summer as determined by Gustajtis and Buckley (1977) based on IIP records during the period January 1963 to February 1977. In this study, summer is defined as the months of May through August. The relative concentration is shown by a gradation of tone ranging from negligible (one iceberg or less per 0.25 latitude-longitude grid square) to extreme (more than 20 icebergs per grid area). A complete legend is given in Appendix A.

For Newfoundland waters, two figures are given in the Appendix which show the average iceberg density per latitude-longitude grid area in the spring and summer; only rarely do icebergs drift into these southern latitudes during the autumn and early winter months. These figures are based on IIP data for the period 1967 to 1977.

3.5 Hours of Daylight

Figure 3.12 shows the hours of daylight and the percentage of daylight hours each day throughout the year for every 5° of latitude from 40° north (N) to 75° N. For example, on the first of May at latitude 40°N, there are approximately 14 hours 35 minutes between sunrise and sunset; this is about 61 percent of the time on that day.

3.6 Summary

For the purpose of sensor evaluation, meteorological visibility and sea conditions are generally the most important. Therefore, the average (50% exceedence) and severe (25% exceedence) visibility, wind, wave, and the

corresponding Beaufort sea state conditions have been calculated from the data in Appendix A for the forecast areas identified in Figure 3.1. From Table 3.2, it is evident that average conditions during summer months are similar throughout the Gulf of St. Lawrence and the continental shelf areas off Nova Scotia and Newfoundland.

This is also true for the more severe winter months. During the winter months average winds are 15 to 20 knots, combined sea and swell heights are between 2 and 2.5 m, and Beaufort sea states range from 4 to 5. In the summer, winds are generally 10 to 12 knots, waves are approximately 1.5 m, and Beaufort sea states are between 2 and 3. Visibility is generally worse in the summer than in the winter for the southern areas, with the reverse true in the north. However, data for the three northern areas (Belle Isle Bank, NW Labrador and Davis Strait) are less reliable due to the presence of ice during the winter and spring periods, and comparatively fewer data points throughout the year.

Recognizing that many accidents may be associated with severe weather, the 25% exceedence visibility, wind, wave, and sea state conditions have been summarized in Table 3.3 It is immediately evident that reduced visibility will severely impede visual searches off Nova Scotia and over the Grand Banks during the summer months, and to a lesser extent, throughout the area during all seasons. Winter winds increase to 25 to 30 knots, waves to more than 3.0 m and sea states to 5 or 6. Severe summer conditions are generally similar to average winter conditions.

Other environmental parameters can be summarized as follows:

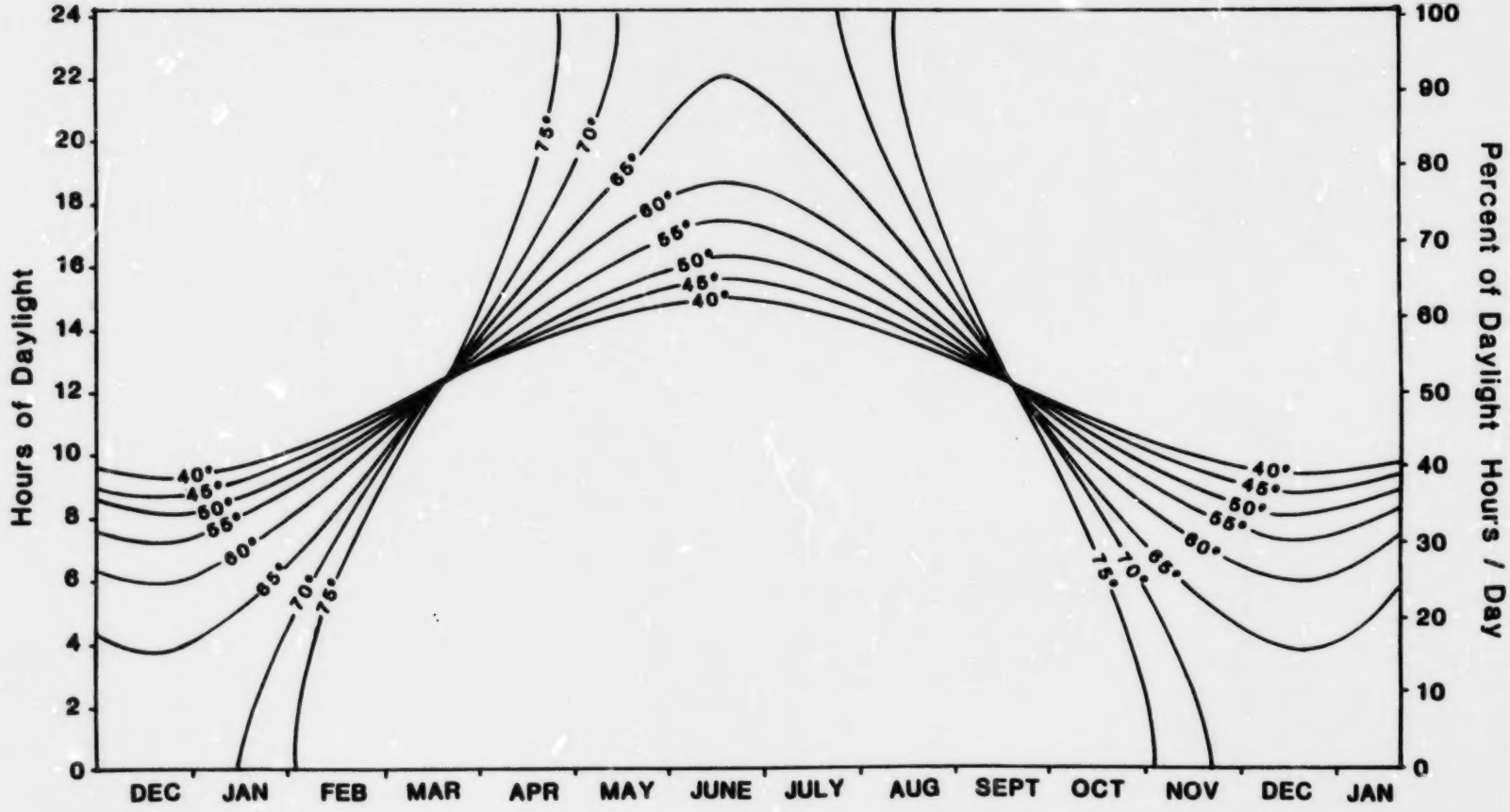

Figure 3.12 - Hours of Daylight (Northern Hemisphere)

AREA	WINTER			SUMMER		
	Wind (Knots)	Waves (Meters)	Sea State	Wind (Knots)	Waves (Meters)	Sea State
Georges Bank	16	2.0	3-4	9	1.2	1-3
Sable	18	2.2	4-5	12	1.4	2-3
Banquereau	19	2.2	4-5	12	1.5	2-3
Gulf-Magdalen	18	2.0	3-4	13	1.4	2-3
SE Grand Bank	17	2.4	4-5	12	1.5	2-3
N Grand Bank	19	2.6	4-5	12	1.7	2-4
Belle Isle Bank*	17	2.2	4-5	12	1.5	2-3
N.W. Labrador*	16	2.0	3-4	14	1.5	3
Davis Strait*	10	0.5	2	10	1.0	2-3

* Conditions in these areas are affected by presence of sea ice, particularly during the winter, and lack of observations throughout the year.

Table 3.2 - **Average (50% Exceedence) Winter and Summer Wind, Wave and Corresponding Beaufort Sea State Conditions for Typical Areas off the East Coast of Canada.**

AREA	WINTER				SUMMER			
	Vis. (km)	Wind (Knots)	Waves (Meters)	Sea State	Vis. (km)	Wind (Knots)	Waves (Meters)	Sea State
Georges Bank	>10	23	2.8	5	<1	13	1.5	2-3
Sable	>10	26	3.2	5-6	<1	16	2.0	3-4
Banquereau	>10	27	3.2	5-6	<1	17	2.0	4
Gulf-Madgalen	5-10	26	3.0	5-6	>10	20	2.0	4-5
SE Grand Bank	5-10	23	3.3	5	<1	16	2.1	3-4
N Grand Bank	5-10	27	3.3	5-6	<1	18	2.2	4
Belle Isle Bank*	5-10	24	3.3	5	3-5	17	2.3	3-4
N.W. Labrador*	3-5	25	2.9	5-6	5-10	20	2.1	5
Davis Strait	5-10	16	0.6	1-3	5-10	16	1.7	3-4

* Conditions in these areas are affected by presence of sea ice, particularly during the winter, and lack of observations throughout the year.

Table 3.3 - Severe (25% Exceedence) Winter and Summer Visibility, Wind and Beaufort Sea State Conditions (for Typical Areas off the East coast of Canada).

(i) Hours of daylight range from 15 during the summer in the south to 24 in the extreme north of the area, and from 9 in the south to zero in the north during the winter months;

(ii) Summer air and water temperatures are similar and range from 17°C in the south to 3°C in the north. Winter air temperatures vary from near zero in the south to -5°C in the Gulf of St. Lawrence and -10 to -15°C offshore Labrador and Davis Strait. Winter sea temperatures range from 2 to 5°C in the south to the freezing point near -2°C in the north.

(iii) Precipitation occurs in the south about 20 to 25% of the time in the winter with rain and snow occurring with nearly equal probability. In summer, precipitation occurs about 5% of the time. Further north, precipitation occurs about 25 to 40% of the time in the winter, and about 10% of the time in the summer months. Snow during the winter months increases from near 10% in the south, to 30 to 40% of the time in the north.

(iv) Freezing precipitation is rare in the south (Georges Bank), the maximum occurrence being between 0.5 and 1% of the time in only one month of the year. This increases to between 0.5 and 1% of the time up to five months of the year further north.

(v) Sea ice is normally present during the winter and spring months in the Gulf of St. Lawrence, and northeast of Newfoundland, and along the Labrador coast. Icebergs are encountered during the spring

and early summer months east of Newfoundland. Off Labrador and Southern Baffin Bay, icebergs occur throughout the year but with minimum concentrations during the autumn.

(vi) The velocity of sound measurements available for the Scotian Shelf and Grand Banks indicate that the ocean is well mixed to at least 75 m during the winter months with an average sound velocity of 1456 metres/second (m/s). Velocities are slightly higher in the south and lower in the north. In summer, the velocities decrease from about 1493 m/s at the surface to 1452 m/s at a depth of 60 m before increasing gradually to 1470 m/s at 225 m. Again, there is a general decrease in velocities from south to north.

4.0 SENSOR SYSTEMS

4.1 Introduction

Table 4.1 is from the NORDCO proposal and identifies the sensors relevant to the small target detection task. In actuality, the near infrared and thermal infrared sensors have been combined in a discussion of forward looking infrared (FLIR) systems, and the visual aids section has focussed on the performance of low light level television (LLLTV). Discussions on radar performance have been limited to that of conventional marine X- and S-band equipment. Acoustic systems are novel to the small target detection application, and so a certain amount of underwater acoustic propagation modelling has been included along with the performance review information. Insufficient information was available to make a passive microwave section worthwhile.

In the following sections, the basic principles of operation for each sensor are provided, along with a discussion of the major environmental effects on the performance of each technique and the major factors affecting the performance of each system on a ship. This is followed by a review of the past performance of the various sensors based on a literature survey and theoretical modelling where possible. The final section is a discussion of the major issues which precipitate from the evaluation of each sensor.

Technique/ Device	Type (Wavelength λ)	Time of Operation (Dependence on Ambient Light)	Weather Effects	Angular Resolution (λ /Aperture)	Remarks
Visual & Near Infrared (VIR)	Passive (0.3 to 1 μm)	Day only (Yes)	Susceptible to cloud, fog, & Precipitation -Reducing Range	Very Good (~ .001°)	Low Light Level Television (LLLTV) Used During Clear Moonlight/Starlight
Thermal Infrared (TIR)	Passive (8 to 14 μm)	Day or Night (No)	Susceptible to cloud, fog, & Precipitation -Reducing Range	Good (~ .01°)	Temperature Difference Aids Detection
Radar	Active (1mm to 1 m)	Day or Night (No)	Virtually Independent of og & Precipi- tation at Selected Wavelengths	Moderate (Small λ) to Poor (large λ) (~1° to 3°)	A Variety of Design Options Available Being An Active System
Acoustic	Active/Passive	Day or Night (No)	Virtually None at Selected Wavelength/ Operations	Moderate to Poor	May Have Limited Range Depending on Prevailing Ocean- ographic Conditions
Passive Microwave	(1mm-1cm)	Day or Night (No)	Slightly	Poor	
Passive Transponder/ Reflector	Passive	Day or Night (No)	Virtually None	Good	Used with Radar, Sonar or other Sensors
Active Transponder/ Beacon (ELT'S/EPIRB'S)	Active	Day or Night (No)	Virtually None	Good	Target Identification Easiest
Radio Transmitter	Active	Day or Night (No)	Virtually None	Poor	Position Location Difficult

Table 4.1 Examples of Candidate Technical Methods of Detection

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4.2 Forward Looking Infrared (FLIR) Systems

4.2.1 Basic Principles of Operation

A FLIR system is an imaging system which senses the thermal radiation emitted by an object. The radiation sensed is usually in the 8 to 14 micron (um) band of the electromagnetic spectrum. The actual amount of thermal radiation emitted by an object is a function of its thermometric temperature (how warm it is) and its emissivity, which is a measure of the amount of energy radiated by the object relative to a standard reference (blackbody) at the same temperature.

A FLIR system operated on a ship or aircraft normally provides a black and white image on a television display very similar to that of a normal television picture. Depending on the polarity used, objects emitting higher radiation levels will appear darker or lighter than the surrounding background. In other words the contrast is created by the thermal radiation difference rather than the light radiation emitted or reflected by the object. For example, using positive polarity, a warm body in the ocean will be brighter than the surrounding ocean because the temperature of the body combined with its emissivity is significantly higher than that of the ocean.

The thermal radiation being detected by a FLIR system is at an extremely low level. Therefore, special techniques have to be utilized for minimizing the thermal noise of the FLIR detection system itself or it will totally mask the incoming radiation. Special techniques are employed to overcome this problem. Basically, they involve cooling the detector down to near absolute zero to minimize the thermal noise generated. Most commercial systems utilize what are

known as open loop or closed loop cooling systems. The open loop system uses liquid nitrogen or some other form of coolant and requires replenishment every few hours or less, while the closed loop system (sometimes called a closed cycle cryogenic refrigerator) can operate maintenance free for many days. The closed loop system is much more expensive initially but may pay for itself in the long term in the savings in coolant costs alone.

The key factors governing the performance of a FLIR system for small target detection at sea are spatial and radiometric resolution. The spatial resolution determines the minimum size object which can be detected and is usually defined in milliradians (mrad), with a good system having values of around 2 mrad or less. The radiometric (or gray tone) resolution determines the temperature differences which can be detected, again in a good system this is about 0.1 to 0.2^{o} Celsius. Utilization of good spatial and radiometric resolutions in a very sensitive system maximizes the ability to detect and classify small targets at long ranges.

4.2.2 Atmospheric Effects on FLIR System Performance

The performance of infrared systems has been found to be independent of darkness, or in other words, it will perform just as well in the daytime as at night. The presence of water vapor in the form of fog and precipitation (rain or snow) will severely limit its detection capability.

4.2.3 Factors Affecting the Performance of a Shipborne FLIR System

A FLIR system deployed on a vessel will be subjected to harsh environmental conditions as well as to the motions of

the ship itself. The environmental conditions, at least for the outboard sensor unit, will include extremes of heat and cold, high humidities, heavy precipitation (both rain and snow), sea spray and icing. The ship's motion will include varying degrees of heave, pitch, roll, and yaw depending on the sea conditions and the particular vessel. Therefore, any shipborne FLIR system must have at least its scanner unit environmently protected. If it is to operate in conditions for which ship's motion would be significant, a stabilization platform will also be required for the scanner. The system also has to be designed to physically survive in these conditions.

4.2.4 Review of FLIR Performance

This section provides the results of a literature review and personal conversations with people on the subject of the shipborne performance of FLIR systems. Although an extensive computerized literature review was undertaken, only a small amount of material was found. A number of probably very relevant documents were identified that described work undertaken by or for the Department of National Defence (DND) and Defence Research Establishment Valcartier (DREV). These however were either classified or confidential and thus were unavailable.

The earliest reference to shipborne FLIR system performance was found in a report prepared by the Naval Ocean Systems Center in the United States (Borough, 1977). The FLIR system was tested with LLLTV as a collision avoidance device for U.S. Navy Hydrofoils. Table 4.2 shows the results of tests using an oceanographic tower and a hydrofoil as platforms. No environmental data are provided in the report and no mention is made as to what the detection ranges given represent (i.e., maximum, minimum,

TARGET	DETECTION RANGE (Km)*
HORIZONTAL LOG	0.9
VERTICAL LOG	2.0
BUOY	2.2
OIL DRUM	2.0
ROW BOAT	2.4
RUBBER RAFT	2.0

(*Km - Kilometre)

Table 4.2 - Shipborne FLIR System Detection Ranges Measured by the U.S. Naval Ocean Systems Centre (Borough, 1977)

average, etc.). A description of the FLIR system was not provided. It was concluded that the FLIR system did not meet the requirements for a collision avoidance system, and an active (laser gated) LLLTV was shown to outperform it.

In 1980 a commercial infrared imaging system was tested in the Eastern Canadian Arctic for shipborne detection of ice hazards (Remotec Applications, Inc., 1981). Although ice hazards are of no direct interest to search and rescue, bergy bits, growlers and small ice floes approximate the size of small boats, life rafts, etc., and many of the results are pertinent to this subject. Also, this is the only major shipborne infrared target detection study found in the open literature.

The results of the tests showed that ice floes and bergy bits had maximum detection ranges in the range of 2 to 5.5 km. in very low sea states (0 to 3). No probability of detection data were provided.

The experiment showed that the average contrast between the target and the background (sea or sky) was inversely related to the ambient air temperature. No systematic effects of sun angle were noted and the system was shown to be equally effective day or night. Because of the low sea states encountered, the effect of sea state could not be determined. The system was found to be ineffective in fog and precipitation. Detection loss in most cases was attributed to decreasing target size rather than thermal contrast.

A discussion of system effects was also given. It was found that the 3.5° and 7.0° fields-of-view were too small and that wider fields-of-view would aid in initial target detection. The resolution available (0.5 mrads) with the

3.5° beamwidth was stated to be the minimum required. The need for a sensor stabilization platform for higher sea states and image processing techniques for improving target detection were noted.

A discussion of the comparative capabilities of a FLIR system and a marine radar system was also given. The radar usually outperformed the infrared system as far as maximum detection range is concerned. It was suggested, however, that at the long ranges, when the instantaneous probability of detecting a target on either sensor is, say 50%, the combined probability of detection using both is 75% or a 25% increase. It was also stated that at short ranges in high sea states at night when sea clutter might preclude radar detection, the infrared system could increase the detection probability from 0 to 50%. The visual like presentation of the infrared system was also stated to be an aid in target classification (in search and rescue situations this would reduce false alarms).

In 1981 the United States Coast Guard (Osmer et al, 1982) evaluated a helicopter borne FLIR system for target detection performance in a search and rescue situation. Many of the results from this work are believed to be applicable to a shipborne FLIR situation because of the low altitudes utilized (60 to 460 m) and the observation that over this range the overall detection performance did not change. The only exception to this was that persons in the water (PIWS) were detected better at the lower altitudes (60 to 150 m).

The FLIR system utilized was a military system manufactured by the Northrop Corporation. It had switchable narrow (10° X 13.3°, with a 3 X magnification capability) and wide (30° X 40°) fields of view (NFOV and WFOV,

respectively) and was mounted on a stabilized platform. Both positive (white-hot) and negative (white-cold) video display capability was possible.

A summary of the detection performances achieved is given in Table 4.3. Cumulative Probability of Detection (CPD) curves were derived. The pertinent conclusions of this work are:

Small Boats and Life Rafts

Sea State - A FLIR system is usable over the range of sea states tested (0 to 1 m).

Day/Night - No difference in detection performance was found between day and night searches.

Relative Bearing of Sun - No effect on detection performance was found for this parameter.

Video Polarity - Both video polarities were found to be equally effective.

PIWS

Sea State - The FLIR system is capable of detecting PIWS in seas up to 0.7 m. In seas with whitecaps, it is unlikely that PIWS will be detected during actual search missions.

Day/Night - No firm conclusions can be drawn regarding this parameter based upon the data collected.

Relative Bearing of Sun - No effect on detection performance was found for this parameter.

SEA CONDITIONS	TARGET TYPE	RANGE OF WIND SPEED (kt)	MEAN WIND SPEED (kt)	RANGE OF SWELL HEIGHT (ft)	MEAN SWELL HEIGHT (ft)	MEAN DETECTION RANGE (nm)	MEDIAN DETECTION RANGE (nm)	MODAL DETECTION RANGE (nm)	PERCENT OF TARGETS DETECTED	NUMBER OF OPPORTUNITIES
CALM (No whitecaps)	15- to 19- Foot Fiberglass Boats	0-9	4.2	0-1.5	0.8	0.9	0.9	0.9	81	72
	4- to 7-Man Life Rafts[1]	0-6	3.7	0-1.5	0.7	0.8	0.8	0.6	89	56
	PIWs	3-11.5	6.7	0-2.0	1.2	0.3	0.2	0.1-0.2	54	175
ROUGH (Whitecaps) present)	16- to 18- Foot Fiberglass Boats	6.5-15	10.9	2.5-3	2.7	0.6	0.5	0.5	52	33
	7-Man Life Rafts	6.5-22	12.3	2.5-3	2.7	0.6	0.5	0.3	70	20
	PIWs	6.5-20	12.2	2.5-3.5	2.9	0.2	0.2	0.1	7	137

NOTE: All ranges are rounded to the nearest 0.1 nm.

[1]Of the 56 life raft opportunities, 16 were 4-man canopied rafts and 40 were 7-man non-canopied rafts.

Table 4.3 - Detection Performance Achieved by USCG Using Helicopter Borne Northrop FLIR System (Osmer et al, 1982)

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Video Polarity - While detection ranges were similar on both polarities, the data indicated that black-hot polarity may be preferable when searching for PIWS.

One general conclusion was that digital image enhancement could help overcome the problem of detection in high sea states. However, even in its present configuration the FLIR system was said to far exceed any other USCG sensor in nighttime detection/classification capability with small, passive (unlit) targets. It was also felt that, based on these tests, this FLIR system would not be superior to a visual search in clear, daylight conditions.

In the sensor operational recommendations, it was stated that:

The WFOV should be used for searching.

The NFOV should be used only for target classification unless a computer-automated scan is developed.

A FLIR system should not be considered an effective search sensor for PIW targets in rough sea conditions (moderate to heavy whitecaps).

Video polarity should be selected on the basis of operator preference, with black-hot favored when searching for PIWS, pending further data collection.

A FLIR system should be considered the primary sensor in night searches for small, passive targets and search planning should be designed to optimize the FLIR system effectiveness under such conditions.

Among recommended system improvements, it was suggested that digital image processing (enhancement and integration) be added to improve detection in rough seas.

In February of 1983 the USCG carried out another field evaluation of a helicopter borne FLIR system (USCG, 1983). This was a much smaller scale project than the previous one and a different FLIR system was utilized (FLIR Systems, Inc., Model 1000A). The helicopter was flown at altitudes of 150 and 300 m. Pertinent conclusions reached as a result of the tests were as follows:

1. This FLIR system is capable of detecting small boats and life rafts at ranges of at least 2.8 km given that they pass within the field of view. This conclusion is valid for the environmental conditions encountered (significant wave heights of 0.5 to 1 m and no precipitation or fog).

2. Under the environmental conditions encountered PIWS are extremely difficult to detect (significant wave heights of 0.5 to 1.2 m, no precipitation or fog) with the FLIR system utilized.

3. Accurate identification and classification of small targets with the field-of-view of this FLIR system is not possible at the search altitudes used in this experiment (range). A wider field-of-view is required for searching and a much narrower field of view is needed for "zooming in" to identify a target.

A number of pertinent observations were made by the investigators as well. It was noted that only 2 of 22 PIW targets were detected on the FLIR system, however, only

slightly more were seen visually, thus this system was almost as effective as a visual observer in daylight. The two PIW detections occured at night, indicating that darkness was not detrimental to the detection capability of the FLIR system. The investigators noted that heat packs were utilized in the Northrop system tests (Osmer et al, 1982) to simulate body heat PIWS. These were not used in this experiment. In the earlier tests the Northrop system was said to be sensitive enough to detect PIWS without heat packs. It was hypothesized that the FLIR system used in this experiment did not have the sensitivity of the Northrop FLIR system and that a more realistic evaluation would have been possible if heat packs had been used in this test. (A comparison of the wave heights in both experiments indicates that the Northrop FLIR System performance was very poor (7% detected out of 137 targets at a mean detection range of 0.4 km) in comparable conditions.) Finally, the investigators in this experiment noted that all the targets detected were indistinct in appearance and required visual confirmation. This lack of a sharp image definition was thought to probably be an advantage in rough seas due to the smoothing effect on the background clutter.

Sperry Marine Systems examined various sensors for their roll in a shipborne integrated lookout system (collision avoidance system) although no actual experimental work was done (Riggs, 1977). In the study infrared scanners were rejected because of the belief that the image would be difficult to interpret, maintenance costs would be high and its performance is severely limited by absorption and scattering in fog and rain. (Sperry is a manufacturer of Low Light Level Television Systems for shipborne navigation aids and the pessimistic evaluation of FLIR systems may be biased.)

The United States Navy (Naval Surface Weapons Centre) are now finalizing the design of a man portable FLIR system for use on their smaller vessels as a Chemical Warfare Detection Device (Harendon, 1985). The system will not be stabilized but will be mounted on a tripod like device to be pointed in any given direction by the operator (who in essence provides stabilization). The FLIR system and a variety of other sensors were tested for this role but all the results are classified. The FLIR system was found to outperform LLLTV in its detection range for all types of targets. The FLIR system is in actuality a Texas Instrument device with a modified cooling system. In one instance the FLIR system was able to detect a harbour marker buoy at 2.7 km at night in zero visibility in fog. No degradation in detection due to sea state was observed and it was suggested that proper use of sensitivity and gain settings would minimize any potential problems.

103 Search and Rescue Squadron is currently testing a helicopter borne FLIR system in Gander, Newfoundland. Although a number of equipment problems have been encountered detection results have been positive, and 4 to 5 m boats have been detected at 4 to 5 km ranges from an altitude of less than 200 m (Mansi, 1985).

A Northrop FLIR system was recently tested as part of an airborne (fixed wing) system for iceberg reconnaissance off the East Coast of Canada. During the tests it was reported that the FLIR system could see targets (ships and icebergs) that were visibly obscured by cloud (Currie, 1985). No other information was provided.

Spar Aerospace Limited has recently been awarded a contract to build FLIR systems for ships of the United States Navy for target detection, classification and

tracking. Spar provided recognition and detection range curves for a man in a lifeboat using a FLIR system currently being developed by the company (Jenkins, 1985). No sea state or sensor height information was given. For this target at the 50 percent probability level the predicted recognition range extended from 1.23 km in very heavy rain (0.5 km visibility) to 1.8 km in clear conditions. The corresponding detection ranges were 1.5 and 4.9 km, respectively. The latter detection ranges are almost triple those obtained by actual measurements in the previously reported experiments.

One only has to scan the defence oriented magazines to find numerous examples of the use of FLIR systems on airborne and shipborne platforms (for example, McClelland, 1985). Many of these and similar systems are now becoming available commercially and are advertised for, among others, their search and rescue applications. Such a commercial marine "thermal imaging camera" has been recently described in a marine industries magazine (Ocean Industry, 1985).

4.3 Low Light Level Television (LLLTV)

4.3.1 Basic Principles of Operation

LLLTV operates in basically the same manner and in the same visible portion of the electromagnetic spectrum as normal television, with the exception that the light detection and amplification system is extremely sensitive. This sensitivity allows the system to provide a normal television like image in almost total darkness.

LLLTV or night vision systems, as they are sometimes called, are available in packages ranging from sophisticated systems with remote imaging or camera units and high

resolution video displays, along with specialized signal processing and enchancement capabilities, to hand held binocular or monocular type devices operating on flashlight batteries. The latter usually has a limited resolution and sensitivity in comparison with the former. A totally passive system (one having no illumination aid what-so-ever) does require at least some level of ambient light (for example, starlight or moonlight). So-called active LLLTV systems use lights or lasers synchronized with the imaging system to extend the detection range and permit the system to operate in total darkness and some adverse atmospheric conditions.

4.3.2 Atmospheric Effects on LLLTV Performance

The detection capability LLLTV, like other sensors operating in the optical portion of the electromagnetic spectrum, is severely limited by cloud, fog and precipitation. Its performance is likely less than that achievable on infrared image systems in these conditions. Also, in the case of LLLTV, ambient light in the immediate vicinity of the camera (for example, vessel lights) can hinder its performance as the unit will automatically reduce its sensitivity to avoid damage to the detection system.

4.3.3 Factors Affecting the Performance of a Shipborne LLLTV

As with a shipborne FLIR system operating in a harsh shipborne environment, a system (other than the hand held type) using an external remote imaging camera must have suitable protection. Like a FLIR system, the system may require stabilization to make it effective in other than low sea state conditions.

4.3.4 Review of LLLTV Performance

The first record of measured shipborne LLLTV performance found in the open literature is in the same collision avoidance system study as that investigated for the shipborne FLIR system (Borough, 1977). Table 4.4 shows the detection ranges achieved using active and passive systems. Again, no environmental conditions are given nor any explanation of the detection ranges achieved. A LLLTV aided by a laser gated illumination system was investigated and found to be too expensive and too bulky. A more cost effective aid was found to be a gated light illuminated system. A LLLTV system equipped with the latter was concluded to be a cost effective collision avoidance system for U.S. Navy hydrofoils.

Sperry Marine Systems, in its study of sensors for an integrated shipborne lookout system (Riggs, 1977) examined LLLTV through the theoretical modelling. Based on this study a laser gated LLLTV was recommended as one of a suite of sensors. Use of the laser was predicted to give visibility ranges in the order of 9 km under clear conditions down to 1 km in thick fog. Even under heavy precipitation ranges of 9 km were predicted. As noted earlier Sperry may have been biased in this study by the fact that it is a manufacturer of LLLTV systems as navigation aids on ships.

The Naval Surface Weapons Center (U.S.A.) evaluated shipborne LLLTV (along with FLIR systems) as a Chemical Warfare Detection Device (Harendon, 1985). It was discarded in favour of a FLIR system because the FLIR system outperformed LLLTV in detection range and was less susceptible to atmospheric conditions. Because of the lack of ambient light on the ocean it was felt that an active

TARGET	OPERATIONAL MODE	DETECTION RANGE (Km)
HORIZONTAL LOG	ACTIVE	1.9
	PASSIVE	0.5
VERTICAL LOG	ACTIVE	3.7
	PASSIVE	1.1
BUOY	ACTIVE	3.7
	PASSIVE	0.6
OIL DRUM	ACTIVE	3.7
	PASSIVE	1.1
ROW BOAT	ACTIVE	3.7
	PASSIVE	0.3
RUBBER RAFT	ACTIVE	3.7
	PASSIVE	0.9

TABLE 4.4 LLLTV Shipborne Detection Ranges Achieved By the U.S. Naval Oceans System Centre (Borough, 1977)

LLLTV would be more feasible for target detection than the passive system. This is, however, a drawback for military applications because of the need to radiate energy. It was stated, however, that under clear conditions even a passive LLLTV might well outperform a FLIR system in the detection of targets equipped with emergency lights.

The USCG is testing laser gated LLLTV for surveillance because it allows them to see identification marks (for example, lettering, numbers, etc.). When monitoring illegal activities a FLIR system would not be able to provide this information (Taube, 1985). The results have yet to be compiled in a report but in one airborne experiment high contrast 30 cm letters could be seen at about 0.9 km.

A variety of tests have been carried out on LLLTV systems by the Canadian Coast Guard over the last year. A Vistar 301 Night Vision System was recently tested on hovercraft and ships in the Vancouver area (Wade, 1985; MacDonald, 1985; Jull, 1985; and Reid, 1985). The passive version of the system was obtained from the manufacturer and, in the hovercraft tests, a Nite-sun light with an infrared filter was used to simulate the infrared illuminator normally used. Table 4.5 shows the detection ranges achieved. It was reported that the picture and range was severely attenuated by spray and that the Nite-sun search-light in all cases provided longer detection ranges than the LLLTV. Other pertinent results reported were that although good picture resolution was achieved, depth perception was a problem and the system was not effective enough for the hovercraft to maintain maximum speed while enroute to SAR incidents. The conclusions from the hovercraft tests (Wade, 1985) seem to be somewhat contradictory: it was stated that "the system proved effective and useful when making beach approaches and

TARGET	DETECTION RANGE (Km)
Deadhead	0.4
5 m. Boat	0.7
Large Ship	1.9+
Small Ship	1.9+
Rock Breakwater	1.7
Hole in Wall (narrow channel)	1.3

NOTE: Same ranges were achieved in both active and passive modes.

Table 4.5 - Average Detection Ranges Achieved by CCG Using Hovercraft borne LLLTV (Wade, 1985)

landings as it was able to pick up deadheads and hazardous rocks very well", while in another conclusion it was stated: "...the Vistar equipment would not increase the effectiveness of the hovercraft". Because the system was not equipped with the illuminator specified by the manufacturer it was felt that the active mode tests could not be considered a fair indication of how the system would perform with the manufacturer's illuminator. It was recommended that the system be tested on other CCG vessels (slower moving ships) in other areas.

Subsequent testing of the Vistar System was indeed done on a CCG ship in the Vancouver area (MacDonald, 1985 and Jull, 1985). In Jull's memorandum it was stated that the equipment could show objects and coastlines at considerable distances that were not visible to the naked eye. It was felt that the equipment had significant potential as a search and navigation aid in confined waters at night. As the system was tested in an area of high background light it was suggested that it also be tested in remote areas away from light sources. MacDonald stated that the tests indicated it could be a valuable addition to the night searching capabilities of certain CCG vessels and that it would be well suited to areas that have some background light. It was felt that the system could be most effective in populated areas where a flare drop is not possible. It was not reported whether this testing was done using a passive or active version of the system.

In a Memorandum prepared by Reid (1985) he stated that as a result of the preceding tests the Vistar system increased the night search capability for PIW'S by 80%, the ability to search under docks, pilings and bridge structures by 90% and the ability to search beaches, and shorelines by 80%. It provided the capability to identify targets

detected on radar and to see navigation hazards (allowing the vessel to travel at full speed with a reduced risk of damage). In general it was concluded to be very valuable for SAR operations in populated areas (large amount of ambient light).

A hand held night vision device was tested by the CCG on a SAR vessel and a buoy tender in the Maritime Region (Barry, 1984 and Dutin, 1985). The device was a Varo Model AN/TVS-5. Both reports concluded that the device was unsuited for shipboard usage in their area of operation. The following test results were reported by Barry.

1. The sight was good for objects at close range and the clarity was excellent. At longer ranges the clarity was drastically reduced and it was difficult to focus the sight.

2. The sight was heavy and awkward to hold. Ideally, but impractical for shipboard use, the sight should be mount on a tripod or similar mount.

3. A temporary impairment of vision was experienced in the eye used which lasted anywhere from three to five minutes depending on the length of time the sight was operated.

4.4 Marine Radar

4.4.1 Principles of Operation

Marine radar is an active microwave remote sensing device. Standard commercial radars transmit energy in the pulsed continuous wave radar mode. In this mode a shore burst of electromagnetic energy is transmitted (typically 1

microsecond long or less) periodically. The pulse consists of a number of cycles of electromagnetic energy at one frequency. The time delay between transmission of the pulse and the return of the reflected pulse from a target is used to determine the range to the target. The characteristics of the return signal (amplitude, statistical variation, etc.) may provide some information regarding the target itself. The pulse repetition frequency (PRF) period or the time period between transmitted pulses determines the maximum unambiguous range to which the radar can detect targets. Most radars operate over a large number of range settings (typically varying from around 0.25 up to 64 nautical miles) with the PRF period fixed by the combination of the maximum range setting and the particular pulse length utilized.

The effective coverage area of a marine radar is only slightly greater than the optical coverage area (about 15%) and depends primarly on the height of the antenna. Except for the case of strong targets which have significant vertical dimensions the detection range will be limited to the radar horizon, generally 20 km.

By mechanically rotating the (transmitting/receiving) antenna or electronically rotating the beam at a constant speed (usually around 20 to 30 revolutions per minute) while transmitting and receiving energy, a 360^{o} view around a ship is obtained. Usually a number of PRF periods are exceeded before the antenna turns through one horizontal beamwidth so that the azimuth resolution is maintained. The returned energy is typically displayed on a cathode ray tube, commonly called a plan position indicator (PPI) display. The PPI shows the returns from targets in polar co-ordinates.

Most marine radars operate with carrier frequencies (frequency within the transmitted pulse) in the S- and X-band regions of the electromagnetic spectrum. Usually they employ frequencies around 3 (S-band) and 9.5 (X-band) GHz, having wavelengths around 10 and 3.2 cm, respectively. Horizontal polarization is usually utilized, although circular polarization is also employed to provide improved performance when precipitation is present.

The ability to detect a target by radar is governed by the signal-to-clutter or the signal-to-noise ratio. Clutter is the unwanted signal returned from the area around a target, while noise is normally system noise generated within the radar. When the clutter is greater than the system noise level it is the limiting factor in detecting a target. If the clutter level is sufficiently high, a target may go undetected. For marine radar, clutter would be the return from the sea surface or precipitation. System noise is the limiting detection factor in the absence of clutter. In a standard radar receiver a signal-to-noise ratio of 10 db is typically required to provide a 50 percent probability of detection for a given target.

The fundamental system parameters governing the operational performance of a basic marine radar are:

1) Antenna Beamwidth - the narrower the beamwidth the better - It is possible to obtain a commercial X-band radar antenna having a beamwidth 0.8^{o}.

2) Frequency - X-band is preferred for detection of small targets at short ranges in sea clutter. S-band penetrates atmospheric precipitation better and is preferable for detecting larger low lying objects at long ranges.

3) Transmitter Power - Increasing the transmitted power will increase the detection capability for weak targets outside the sea clutter area (doubling or tripling the power is required before significant differences will be found).

4) Pulse Length - In clutter, shorter pulse lengths will give better detection capability.

5) PRF - A higher PRF is better for detection of weak targets outside the sea clutter area.

6) Display - A larger PPI display is preferred to show more detail and to ensure that the spot size is close to or less than the resolution cell size at each range setting.

Many marine radars are equipped with clutter reduction controls to reduce high sea clutter (Sensitivity Time Control or STC) and precipitation clutter (Fast Time Constant or FTC) levels when they appear. The problem with these is that the target signal-to-clutter ratio has to be significant (a relatively strong target) or these controls will tend inhibit detection of the target as well. Also, in recent years Automatic Radar Plotting Aids (ARPA'S) have been added to radars for the automatic detection and tracking of targets. Again, unfortunately, they only work for relatively strong targets and often ignore weak targets. For example, it has been shown operationally that ARPA's are unsuitable for tracking icebergs, particularly bergy bits and growlers, because of their weak target strength.

4.4.2 Environmental Effects on Radar Performance

Sea clutter and precipitation clutter adversely affect the ability of a marine radar to detect a target mainly

because the returned signal level from the clutter tends to mask the target. The amount by which sea clutter affects detection depends on the target strength and the sea state, but for moderate sea conditions this problem usually only occurs in the very near ranges (less than 1 km). As with sea clutter the effect of precipitation clutter on target detection will depend on the amount of precipitation. Usually light rain or snow has a negligible effect. However, precipitation also attenuates the radar signal, although this effect will only be significant for heavy precipitation over major portions of the radar coverage area. Unlike sea clutter, which will occur as an approximate circular area of varying radius round the centre of the PPI display, precipitation clutter depends on the areal extent of the precipitation. It can occur anywhere in the radar coverage area and may even mask the entire display.

Thick fog will also effect the radar performance in that it will cause excess attenuation in the signal. In most situations its effect is only significant at longer ranges.

One atmospheric condition which is largely ignored, but which can have a major effect on a radar's detection capability for surface targets, is the vertical variation in the temperature, humidity and barometric pressure. The combination of these three conditions determines the vertical microwave refractive index profile, which in turn determines the degree and direction in which the radar beams will be "bent." Subnormal propagation conditions occur when the rays are bent excessively upwards, reducing the radar's coverage area on the surface and its capability to detect low lying targets. It has been determined that this condition is predominant in the Grand Banks region during the spring (Budinger, 1960).

So-called "surface ducts" can also be created by this phenomena as well. These ducts start at the ocean surface and extend upwards from as little as 2 to 3 m to 100 m or more, depending on the particular situation. Their effect on radars located within the duct is to act as a wave guide, resulting in the attenuation caused by spreading to be inversely proportional to range to the second power (cylindrical spreading) as oppposed to the normal range to the forth power (spherical spreading). This results in longer ranges of detection. However, the range of significant sea clutter will also increase, meaning that weak targets may be masked by sea clutter at longer ranges. If the radar antenna is located above the duct, depending on the so-called "strength of the duct," the radar rays may not penetrate through it, resulting in a reduced ability to detect weak, low lying targets.

Problems caused by the vertical and spatial variations of the microwave refractive index are considered significantly important in the effect on military shipborne surveillance radar. Onboard processing of atmospheric data is routinely used to predict its effect on the radar performance.

4.4.3 Factors Effecting the Shipborne Performance of a Marine Radar

The major factor affecting the performance of a shipborne marine radar is ship's motion, particularly in higher sea states. The antenna units of most (if not all) commercial systems are not stabilized to minimize the effect of ship's motion. Marine radars operate with a wide vertical beamwidth (15 to 20^{o}) to compensate for this. However, this has been found to be inadequate. The actual

effect can be visually seen on a PPI display, where, depending on the conditions, sections may be blank and unrecognizable returns are seen in others. The onset of significant performance degradation usually depends on the ship's motion characteristics as a function of sea state.

4.4.4 A Review of Marine Radar Performance

The only major study found in the open literature on the performance of shipborne marine radars in a search and rescue mode was undertaken by the USCG in 1980 and 1981 (Osmer et al, 1982). Two standard marine radars were tested using three different vessels (a 12 m utility boat (UTB) and a 25 m and 29 m patrol boat (WPB)). Table 4.6 shows the critical specifications of the two marine radars tested. Tables 4.7 and 4.8 show the targets tested and summarize the results of detection runs. Cumulative Detection Probability Curves (CDP), Lateral Range Curves, and sweep widths were derived. Table 4.9 compares marine radar sweep widths with those using visual observers.

The relevant conclusions from the study are as follows:

Radar type - Search units equipped with the AN/SPS-64(V) radar detected small targets at significantly longer ranges than did units equipped with the AN/SPS-66. Similar CDPs were achieved with both radars for targets with closest points of approach (CPAs).

Radar reflectors - With the exception of the metallized fabric canopy, all radar reflectors tested provided significant improvements in target detection probability. Limited data indicated that a six-foot steel post improved radar detectability as much as some radar reflectors.

PARAMETER	AN/SPS-66(V) (RAYTHEON MODEL 3100)	AN/SPS-64(V) RAYTHEON MODEL RM 1220/6XR
ANTENNA		
Beamwidth	3.5^{o}	1.2^{o}
Gain (DB)	24	28.5
Polarization	Horizontal	Horizontal
Rotation Rate (RPM)	30	33
TRANSMITTER		
Frequency	X	X
Peak Power (KW)	7 KW	20 KW
Pulse Lengths (us)	0.1/0.6	0.6/0.5
Pulse Repetition Frequency (HZ)	1500 to 3000 (0.1 us)	3600 (0.05 us)
DISPLAY		
Type	7" PPI	12" PPI

Table 4.6 - Critical Specifications of the Marine Radars Tested by the USCG (Osmer et al, 1982)

TARGET DESCRIPTION			TOTAL OPPORTUNITIES	NUMBER OF DETECTIONS	PERCENT DETECTED	MEAN DETECTION RANGE (nm)	MEAN SWELL HEIGHT (ft)
SMALL BOATS	14- to 16-foot fiberglass outboard	without reflective equipment	33	8	24	1.1	1.1
		without reflective equipment; 6-foot wooden post installed	6	1	17	1.9	1.2
	16- to 18-foot fiberglass outboard	with engine	29	6	21	0.8	1.8
	14- to 16-foot fiberglass outboard	with 6-foot steel post installed	5	5	100	1.1	0
		with steel post and 12-inch Echomaster radar reflector	5	5	100	0.9	0
		with wooden post and 12-inch Echomaster radar reflector	11	6	55	0.9	1.4
		with wooden post and 11-inch Davis emergency radar reflector	3	1	33	1.3	2.5
		with wooden post and Radark radar reflector	8	2	25	0.8	3.4
LIFE RAFTS	7-man non-canopied life raft	without reflective equipment	23	11	48	0.7	1.1
		without reflective equipment; 6-foot wooden post installed	6	1	17	0.4	1.7
		with 6-foot steel post installed	6	4	67	1.1	0.7
		with steel post and 12-inch Echomaster radar reflector	7	6	86	1.2	0.6
		with steel post and Norin gold-screen radar reflector	7	7	100	1.1	0.6
		with wooden post and 12-inch Echomaster radar reflector	6	2	33	1.0	1.7
		with wooden post and 11-inch Davis emergency radar reflector	21	6	29	1.0	2.5
	4- to 6-man canopied life raft	without reflective equipment	19	8	42	1.1	1.5
		with Mobay metallized fabric canopy	17	8	47	0.8	1.6

Table 4.7 - Detection Performance Summary For AN/SPS-66 Marine Radar (Osmer et al, 1982)

TARGET DESCRIPTION			TOTAL OPPORTUNITIES	NUMBER OF DETECTIONS	PERCENT DETECTED	MEAN DETECTION RANGE (nm)	MEAN SWELL HEIGHT (ft)
SMALL BOATS	14- to 16-foot fiberglass outboard	without reflective equipment	31	16	52	1.2	1.1
		without reflective equipment; 5-foot wooden post installed	6	2	33	1.9	0.9
	16- to 18-foot fiberglass outboard	with engine	29	10	34	1.4	2.0
	14- to 16-foot fiberglass outboard	with 6-foot steel post installed	3	3	100	2.4	0.3
		with steel post and 12-inch Echomaster radar reflector	3	3	100	2.8	0.3
		with wooden post and 12-inch Echomaster radar reflector	11	9	82	2.2	1.1
		with wooden post and 11-inch Davis emergency radar reflector	3	0	0	-	2.5
		with wooden post and Radark radar reflector	11	4	36	2.0	3.2
LIFE RAFTS	7-man non-canopied life raft	without reflective equipment	19	9	47	1.7	1.2
		without reflective equipment; 5-foot wooden post installed	5	1	20	0.9	2.0
		with 6-foot steel post installed	3	2	67	2.0	0
		with steel post and 12-inch Echomaster radar reflector	3	3	100	2.2	0
		with steel post and Yorin gold-screen radar reflector	3	2	67	2.3	0.3
		with wooden post and 12-inch Echomaster radar reflector	5	1	20	1.5	2.0
		with wooden post and 11-inch Davis emergency radar reflector	21	11	52	2.3	2.6
	4- to 6-man canopied life raft	without reflective equipment	15	5	33	2.0	1.6
		with Mobay metallized fabric canopy	11	2	18	2.4	1.7

Table 4.8 - Detection Performance Summary For AN/SPS 64(V) Marine Radar (Osmer et al, 1982)

SENSOR	TARGET DESCRIPTION	VISIBILITY/CLOUD COVER					
		10 nm/0%		5 nm/50%		1 nm/100%	
		WIND SPEED/SWELL HEIGHT		WIND SPEED/SWELL HEIGHT		WIND SPEED/SWELL HEIGHT	
		≤10kt/≤1ft	15kt/2-3ft	≤10kt/≤1ft	15kt/2-3ft	≤10kt/≤1ft	15kt/2-3ft
VISUAL SCANNERS 82-foot WPB / 41-foot UTB	16-foot white boat or 4- to 6-man life raft with orange canopy	4.6[1] / 3.3	2.2[1] / 1.7	3.2[1] / 2.6	1.2[2] / 1.2	1.2[2] / 1.2[1]	0.4[2] / 0.4[1]
	16-foot blue boat or 7-man orange life raft without canopy	4.0[1] / 2.7	1.7[1] / 1.3	2.6[1] / 2.2[1]	0.9[2] / 0.9	1.0[2] / 1.0[2]	0.3[2] / 0.3[1]
	7-man black life raft	3.7[1] / 2.6	1.5[2] / 1.2	2.4[1] / 2.0[1]	0.8[2] / 0.8	0.9[2] / 0.9[2]	0.3[2] / 0.3[1]

RADAR TYPE	TARGET DESCRIPTION	SWELL HEIGHT	
		0 to 2 ft	2.5 to 4 ft
AN/SPS-64(V) (82-foot WPB)	Small boats and life rafts without radar reflectors	2.0	1.8
	Small boats and life rafts with radar reflectors	6.3	2.7
AN/SPS-66 (41-foot UTB)	Small boats and life rafts without radar reflectors	1.3	-0
	Small boats and life rafts with radar reflectors	2.5	0.6

NOTES: Time on task (time searching) is assumed to be 2 to 4 hours for all visual sweep widths.

Radar sweep width calculations assume that the target moves from R_{max} ahead of the search unit through CPA to $-R_{max}$ beyond the search unit along a straight path and that the radar operator scans the entire PPI display uniformly. No precipitation effects are considered.

[1]Radar search is preferred only if the target has a radar reflector.

[2]Radar search is preferred even if the target has no radar reflector.

Table 4.9 - USCG Comparison of Marine Radar Sweep Widths With Visual Sweep Widths (Osmer et al, 1982)

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Environmental conditions - Swell height, which determines the amount of sea-return clutter present on the PPI display, significantly reduced radar search performance. The effect of this parameter far outweighed the influence of other variables (wind speed, precipitation, humidity) over the range of values tested.

Sweep widths -

1) Sweep widths for search units with the AN/SPS-64(V) are approximately twice those for units with the AN/SPS-66 in calm (0- to 2-foot) seas. In rougher (2.5- to 4-foot) seas, AN/SPS-64(V) sweep widths are four to five times greater than those achieved with the AN/SPS-66.

2) In calm seas, radar reflectors tripled the sweep widths achievable by search craft with the AN/SPS-64(V); sweep widths with the AN/SPS-66 were doubled by the use of a radar reflector. Sweep widths were increased about 50 percent with the AN/SPS-64(V) when a radar reflector was used in rough seas. Search units equipped with the AN/SPS-66 were unable to detect a small target in rough seas unless the target was equipped with a radar reflector.

3) Rough seas reduced AN/SPS-64(V) sweep widths 10 to 20 percent for small targets without radar reflectors and 60 to 70 percent for targets with radar reflectors. The AN/SPS-66 radar was not an effective small target search sensor in seas greater than two feet.

Range scales - With both the AN/SPS-64(V) and AN/SPS-66 radars, the 3-nmi range scale provided better search performance than the 6-nmi scale.

29-Metre WPBs - Limited data collected in calm seas indicated that 29-metre WPBs achieved better search performance than 12 m UTBs when both were equipped with the AN/SPS-66 radar. Installation of the AN/SPS-64(V) on 29 m WPBs should provide a significant improvement in small-target detection range capability and sweep width.

Sea Clutter Reduction - Heavy sea-return clutter (in seas greater than 10 m) could not be reduced to an acceptable level on either radar without reducing radar sensitivity (STC) below that required for small-target detection.

Some of these conclusions are worthy of further discussion. With regard to radar type, examining Table 4.9 and noting statements made in Section 4.4.1 regarding critical parameters, it is obvious that the AN/SPS-64(V) radar should provide longer detection ranges than the AN/SPS-66 because it is a higher performance radar. Also the antenna height used with the AN/SPS-64(V) was almost triple that of the AN/SPS-66 radar (12 m as opposed to 4.6 m), which increases the horizon distance. In the absence of sea clutter this will result in longer detection ranges and hence greater sweep widths. In sea states higher than those encountered during the tests the height advantage may be offset somewhat when attempting to detect small targets because the higher incidence angles of the radar beam with the ocean surface will result in the sea clutter levels being higher.

The improved performance of both radars on the three nautical mile range scale was considered by the investigators to be due to several factors. It is felt that the overriding factor was that both radars operated with

their highest PRF at the shortest pulse length (smallest range resolution) on this scale. Of secondary importance is the size of the coverage area relative to the PPI size.

The improved performance of the AN/SPS-66 radar on the 29-metre WPBs over the 12 m UTB's in calm seas is most likely solely due to the antenna height difference. In this case the advantage may be totally negated when attempting to detect targets in sea clutter for reasons already provided above.

The conclusion with regard to the sea clutter reduction control (STC) not aiding detection verifies the statements made regarding the use of clutter controls for weak targets in Section 4.4.1.

A conclusion on the effectiveness of radar over visual detection was not given, but referring to Table 4.9 it can be seen that in the conditions examined the radar outperformed a visual observer (scanner) in 39 percent of the cases if the target had a radar reflector and 33 percent of the cases independent of whether the target had a reflector or not. At night the radar would no doubt outperform the visual observer in all cases.

As part of its integrated lookout system study Sperry Marine Systems investigated an optimum radar system. A dual radar system was said to be required. An S-band radar was selected for detection of larger surface targets at long ranges (radar horizon). An X-band system was selected for the detection of buoys and other small low-lying objects. In addition to the basic radar parameters it was determined that the S-band system should have a very low scan rate (6 rpm), a low PRF rate (244 Hz), pulse-to-pulse integration and a distribution free detector (independent of the

statistics of the sea clutter). The additional requirements for the X-band system were stated to be circular polarization, a low PRF (163 Hz) a high scan rate (120 RPM) back and forth across a 15^{o} steerable sector, scan-to-scan integration, pulse-to-pulse integration, and a distribution free detector. Digital video processing was specified along with a special video display monitor. A capability for overlaying the one radar image on the other was said to be required.

In a theoretical and experimental program undertaken in 1979 and 1980 (Remotec Applications, Inc. 1981) towards development of a shipborne ice hazard detection system the need for scan-to-scan and pulse-to-pulse averaging and various image enhancement routines was stated. Also, the need for both S- and X-band radars along with television like displays was identified.

Viatec Resource Systems Inc. (Harvey, 1983) undertook a review of the Remotec work and basically agreed with the radar system required. A variety of other investigations have demonstrated the significant improvement in detection probability and maximum detection range using the special processing techniques already described, along with better displays, frequency, height and polarization diversity, and judicious selection of basic radar parameters (see, for example, Croney et al., 1975, and Williams, 1979;). Despite all these results apparently only one company, the Japan Radio Corporation, is offering a commercial marine radar with any of the special processing techniques described.

In tests of airborne surveillance (or forward looking) radars for target detection in search and rescue operations the USCG (Ketchen et al, 1984) demonstrated that the APS-134 radar equipped with many of the processing techniques

mentioned significantly outperformed other radars not so equipped. Sweep widths obtained were at least a factor of four better.

4.4.5 Active Radar Reflectors (Radar Transponders)

A review of all the past search and rescue detection work using radar failed to show any usage of active radar reflectors or transponders to improve detection performance. In a discussion with USCG personnel, it was indicated that all their studies are geared to short range detection of small objects not equipped with special devices (Hayes, 1985). The philosophy is that the Search and Rescue Satellite (SARSAT) used in conjunction with Emergency Position Indicator Radio Beacons (EPIRB's) and Emergency Locator Transponders (ELT's) will be almost totally utilized in the future and that only in situations where no location devices are being utilized will the USCG have to conduct the searches described.

Only one company, the Mitsubishi Electric Corporation, was found that advertised Radar Transponders for search and rescue purposes. The unit is called a MELSWEEP transponder and operates in the X-band frequency range. It has two major functions:

1) It informs distressed persons of the approach of a vehicle (operating a radar) by visual and audible alarm; and

2) It indicates the presence of distresssed persons on the radar scope of the approaching vehicle.

One model (H) is designed for small boats not equipped with life rafts, while the other (K) is designed for

mounting on liferafts. Actual detection range curves provided by the company for a sea state between 1 and 2, and a radar antenna height of 15.0 m show that at the 50 percent probability of detection level a Model K unit on a liferaft can be detected at 18.5 km, while a Model H unit in the water is detectable at 5 km. The Model K unit appears to be a considerable improvement over that achieved by the USCG using passive reflectors (see Tables 4.7 and 4.8). The Model H unit results cannot be directly compared with the USCG measurements.

The units are bulky and, depending on the model, have two or three components. The costs are unavailable at this time.

4.5 Underwater Acoustic Systems

4.5.1 Basic Principles of Operation

Both active and passive underwater acoustic systems are examined in this section, both target mounted and shipborne. The three basic combinations of acoustic detection systems considered are:

1) Shipborne active sonar against object in water;

2) Shipborne active sonar against object with active or passive
acoustic target;

3) Shipborne passive acoustic system against object with active
acoustic target.

An active sonar system operates in a manner analogous to a radar. It transmits a pulse (usually 1 millisecond (ms) or less) containing a number of cycles corresponding to a particular acoustic frequency (approximately 5 to 400 kHz). The pulse propagates through the water and the range to an object is determined by the time delay between transmission of the pulse and reception of the pulse after reflection of the object. The frequency and beam pattern utilized are dictated by the range requirements, and the application (bottom mapping, sounding, fishing finding, submarine hunting, etc). The source level is usually as high as possible with the level at which water cavitation occurs on the face of the transducer being the upper bound. The display can be a PPI type, a television monitor, or a gray scale hard copy readout.

A passive acoustic system detects underwater sounds in a specific acoustic band. Range cannot be measured directly but the combination of bearing discrimination with multiple fixes can provide positional information. In order to detect an object in the water with a passive system the object must be radiating acoustic energy of a sufficient level and in the frequency range for which the receiver is sensitive.

Passive acoustic targets would be constructed of a material and would be of such a shape so as the maximize their acoustic reflectivity. They may be designed for maximum reflectivity in a certain direction or to be omnidirectional.

Active acoustic targets are classed as either pingers or transponders. Both usually transmit pulses of acoustic energy at a specific frequency (just as an active acoustic system would) omnidirectionally or at least omnidirectionally in the horizontal plane. A pinger transmits pulses at a predetermined interval once it is activated. A transponder, however, only transmits a pulse when it receives an acoustic pulse of the correct frequency (in other words when it is interrogated) and therefore requires a receiving capability. An active acoustic shipborne system must be used in conjunction with a transponder. Transponders and pingers can effectively achieve much higher target strengths than passive acoustic targets of comparable size. These active devices can also be made very small. For example, one pinger available commercially is approximately 33 cm long and 1 cm in diameter.

4.5.2 Environmental Factors Affecting the Performance of Underwater Acoustic Systems

The major factor affecting the performance of an underwater acoustic system is the variation in the sound velocity with depth. The velocity at any given depth can be determined from the salinity and water temperature as well the depth itself. The effect of this velocity variation with depth on the propagation of sound waves is analogous to the effect the variation in the microwave refractive index profile has on radar propagation: it can cause horizontally radiated sound rays to be trapped in a layer adjacent to the surface (usually called the mixed surface layer), or the rays may be bent excessively towards the bottom over a very short horizontal range. Such conditions will significantly effect the horizontal range at which an object will be detected. Typical salinity, temperature and velocity profiles for the area of interest were provided in Section 3.0.

As with radar detectability, underwater acoustic signal detection depends on its signal-to-noise (system noise) or signal-to-clutter (unwanted returns from other unwanted targets) ratio. In the acoustic field clutter is called reverberation and in this case surface reverberation (return from the underside of the ocean surface) is the limiting factor. The surface reverberation is primarily a function of sea state and incidence angle of the acoustic energy at any given frequency.

4.5.3 Factors Affecting the Performance of a Shipborne Underwater Acoustic System

An acoustic transducer can be mounted on the hull of ship, towed, or lowered over the side. Normally, hull

mounted search sonars transducers are designed to protrude through the ships hull below the keel when in operation. This, however, limits its deployment to one water depth which may not be the optimum depth when the sound velocity profile is considered. A towed transducer (or transducer array) gives flexibility for varying the depth but requires that the ship be in motion at a fairly constant speed at all times. Lowering a transducer over the side would normally require that the ship be stopped although a slow speed may be tolerable. This latter case also gives depth flexibility. High sea states would probably preclude the deployment of an over-the-side system or a towed system.

Accustic systems are normally designed so that the effect of ship's noise is minimized. Ship's motion will have an effect on the instantaneous bearing information provided by any hull mounted acoustic system.

4.5.4 Review of Underwater Acoustic System Performance

A comprehensive literature review failed to show up any experimental studies on the use of acoustics for the shipborne detection of small objects in the ocean in a search and rescue situation. In order to obtain some indication of what the performance might be, theoretical modelling work was undertaken and the performance of acoustic tracking systems was investigated through discussions with an acoustic expert.

A description of the theoretical acoustic modelling work is given in Appendix B. The results show that using an active underwater acoustic system to detect a passive, floating object or a passive acoustic target suspended in the water column is not feasible. At best ranges of much less than 0.5 km can be expected assuming reasonably sized

objects. Using acoustic transponders or pingers as targets in a sea state 3, it is shown that detection ranges of up to 3.7 km are possible when realistic system parameters are utilized at a frequency of 50 kHz. The modelling work also showed that when conditions might preclude the direct detection of an active target floating near the surface (high sea states) utilizing reflections off the bottom (bottom bounce) ranges of up to 1.7 km are achievable.

In discussions on acoustic tracking systems (McKeown, 1985) it was found that at frequencies between 22 and 30 kHz pingers mounted 0.5 m below the surface on drifting buoys could be tracked reliably out to ranges of 2 km with maximum ranges of around 3 km. Such ranges were achieved in moderate sea conditions. The work referred to was undertaken on the Scotia Shelf and in the Southern Grand Banks Region.

To obtain some indication of propagation conditions due to the velocity profile predicted ray paths were generated using representative sound velocity profiles from the regions of interest (Scrimger, 1979). They indicate that the worst propagation conditions exist in the spring and the best conditions exist in the summer. They also indicate that through utilization of shallow deployment depths (less than 5 m) and proper selection of a vertical beam pattern (for both active and passive sonar systems) a maximum detection range of about 1 km can be achieved for near surface targets. In light of the experimental data collected by McKeown it would appear that these ray path predictions may be somewhat pessimistic or that deployment depths much less than 5 m (say 1 m), which were not tested with the velocity profiles, may give greatly improved results.

4.6 Discussion

Some general comments and conclusions can be made for each of the various sensors investigated. These are discussed in the following subsections. The last subsection considers more general observations.

4.6.1 FLIR Systems

A high performancce, helicopter mounted FLIR system has been shown to be effective for short range (less than 5 km) day or night detection of targets in sea states less than or equal to 2 - at higher sea states, whitecaps reduce its detection capability. From the helicopter tests, it appeared range increased with decreasing sensor height. Therefore, it is possible that the effective range for a shipborne sensor might be greater than that for the helicopter mounted system. However, the shipborne system will be more sensitive to the problem of sensor-target intervisibility as the wave heights increase.

The detection results for boats and PIWS were obtained in much warmer climates (off New York and Florida) than those which might be expected off the East Coast of Canada. Consequently, both the target and the sea surface temperatures will probably be significantly colder. This may reduce the detection performance of a FLIR system somewhat in that the system minimum detectable temperature difference may be greater and the actual signal-to-noise ratio will be lower.

Increased ship motion as the sea state increases will also detract from FLIR system performance, so a stabilized platform or sensor aiming system may be mandatory. Image processing techniques, such as integration or averaging of

successive images, might also improve detection of small objects in rough seas, provided image-to-image stability can be achieved.

It was observed in the FLIR system tests that the narrow field-of-view was practically useless in the search mode, it being more suitable for detection confirmation and classification. The wide field-of-view was felt to be more suited for this search. As the resolving power of the sensor is inversely related to the field-of-view, this results in a reduction in detection capability in the search mode, the situation in which such power is most required. Therefore, it is crucial that in the selection of a system the resolving power associated with the wide field-of-view rather than with the narrow field of view be looked upon as the limiting resolving power of the system, the goal being to maximize it.

Reports of FLIR systems being able to detect objects through fog and cloud warrant further investigation as this capability could be very important during the periods of fog common off Nova Scotia and Newfoundland. Finally, the emphasis military organizations are placing on FLIR system development and usage suggests infrared systems have potential for target detection, but the temperature contrasts in a SAR situation may be very much smaller than those anticipated in military targets. Before a final decision is made on the effectiveness of FLIR, a review of classified military literature should be undertaken.

4.6.2 LLLTV

It is clear that a passive LLLTV is not an effective SAR sensor for detecting small objects in an area of little ambient light. However, contradictory results render it

impossible to make a clear statement of the effectiveness of an active LLLTV. The U.S. Navy hydrofoil collision avoidance test results clearly indicate the superiority of the active LLLTV system over a passive LLLTV and a FLIR system. However, the CCG test results for the active version of the VISTAR system were pointed out to be probably invalid because the manufacturer's illumination system was not used. The apparent lack of interest in active LLLTV by the military may be due to the need to radiate energy rather than to inadequacies in the technology for detecting targets. The only clear conclusion is the need for a proper comprehensive test of an active LLLTV system.

4.6.3 Marine Radar

Using well trained operators, marine radar has been shown to outperform visual observers in many situations in low to moderate sea states (0 to 3) even in clear daylight conditions. They, therefore, will be a definite asset in similar sea conditions at night or in reduced visibility.

It is apparent that by judicious selection of system parameters, an optimum basic marine radar can be configured. It is also clear that the addition of high speed scanning (scan-to-scan and pulse-to-pulse averaging, etc.), sophisticated processing techniques, improved raster scan displays, multiple radar scanners, frequency diversity, and polarization diversity will significantly improve the maximum range of detection, detection in clutter and the overall probability of detection over that of even an optimized basic marine radar. Such sophisticated radars are already utilized in the military.

The use of passive radar reflectors on life boats and rafts significantly improves their detectability. If an

effective reflector could be designed to be carried in an immersion or floatation suit or a life jacket it would no doubt improve the detection performance against PIWS as well. The only information found regarding active radar transponders suitable for search and rescue application was that provided by one manufacturer. The predicted improved performance warrants further investigation under environmental conditions in the region of interest. The size and cost may make their usage prohibitive in many small vessel operations.

Finally, to obtain quantitative information on sweep widths applicable to the East Coast of Canada experimental programs similar to those undertaken by the USCG need to be carried out using typical Canadian equipment under representative Canadian environmental conditions.

4.6.4 Underwater Acoustic Systems

Limited results indicate that an underwater acoustic system consisting of a shipborne sonar and a transponder attached to the object to be detected, or a shipborne passive listening system with a pinger attached to the target, may be very effective in SAR operations. Ranges of 2 km look to be reliable based actual experimental data. Theoretical modelling in conjunction with ray path predictions using typical sound velocity profiles suggest that ranges of 1 km or more are possible provided the shipborne and target unit are kept less than 5 m below the surface. More extensive measurements need to be made to determine more accurate performance estimates.

Because of the small size of acoustic pingers and the virtual independence of an underwater acoustic system's performance on atmospheric conditions, this detection

technique may be very attractive in very poor visibility conditions (fog and precipitation). Such conditions would render the FLIR and LLLTV virtually inoperable and in certain cases reduce the radar performance as well.

4.6.5 General Observations

A major problem with the shipborne operation of all the sensors considered is that ship's motion in higher sea states will potentially render the sensors ineffective. Even a sophisticated platform stabilization or sensor aiming system, may not be adequate for the operational conditions anticipated off the East Coast.

The question of target of identification/classification has not been extensively addressed. Identification was noted to be a problem with one of the FLIR systems, while it was stated in one of the tests that LLLTV could be used to identify targets detected on the radar. It is doubtful that target identification will be possible on the radar. An acoustic system utilizing pingers or transponders would provide an immediate identification (or at least classification). The lack of identification or classification capability could potentially be a problem in the areas frequented by pack ice and icebergs because of the significant probability of false alarm during certain seasons.

5.0 ESTIMATION OF SWEEP WIDTHS

5.1 Introduction

The term "sweep width" is defined graphically in Figure 5.1. It is the width of the corridor that can be searched from a vessel with some known chance of success. With this corridor, the probability of detecting a given target under the prevailing environmental conditions is such that the number of targets missed within the corridor equals the number that might be detected between the limits of the corridor and the maximum detection range. The procedure for calculating the width of the corridor for any given search situation is based on experience for visual sweep widths, lately supplemented by experimentally derived statistical models such as those used by the USCG.

In the following section, sweep widths have been calculated for visual searches using the standard CCG SAR Manual tables under average and extreme environmental conditions off the east coast. The targets are similar to, but not necessarily identical to those identified in Section 2 of this report. The reason for the discrepancy is the lack of correspondence between the selected targets and those used in the SAR Manual tables. The results of these basic calculations are then reviewed in the light of recent USCG experimental data and the lookout-target inter-visibility modelling by NORDCO.

With regard to remote sensing techniques for target detection, experimentally based statistics are available for radar under low sea state conditions, but not for sea states typical of those encountered off the coast of Canada during

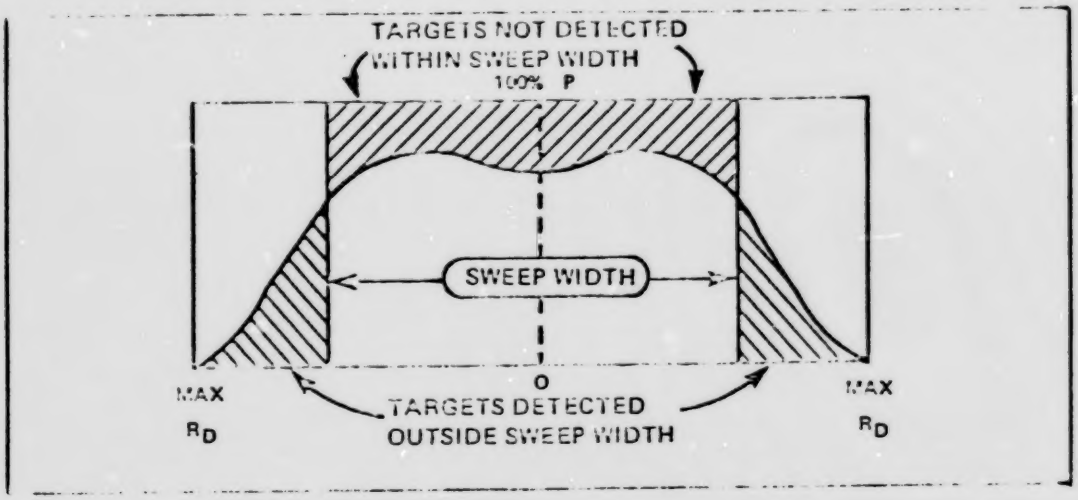

Figure 5.1 Graphic Presentation Of Sweep Width (Osmer et al, 1982)

the winter. Therefore, NORDCO's radar model has been modified to give the instantaneous probability of detection for a given target under particular environmental conditions. These statistics are not the same as the experimentally derived cumulative probability of detection used by the USCG to derive sweep widths, but can give an approximate idea of sweep widths to be expected using the same radars under Canadian conditions.

Data for sweep width calculations for FLIR, LLLTV, and acoustic systems are not available, so the maximum range information discussed in the previoius Section remains the only guide to the performance of such sensors. The Section ends with a qualitative discussion of the relative magnitude of sweep widths using visual and remote sensing techniques under different environmental conditions.

5.2 Visual Detection of Sweep Widths

Visual search sweep widths calculated in accordance with the CCG SAR manual for east coast offshore environmental conditions are used as the standard in assessing the effectiveness of remote sensing techniques. Typical sweep widths for various detection aids for day and night searches under good weather conditions are given in Table 5.1.

Sweep widths (Wu) calculated from the SAR Manual tables (USCG, 1973) for the standard targets used in this report are given in Table 5.2. However, these values must then be modified in accordance with Tables 5.3 and 5.4 (also from the SAR Manual) for the 50 and 25 percent exceedence conditions for wind/waves (fw) and cloud cover (fr). No cloud data are available for the east coast so this factor, which is generally 1.0 has been ignored. The results are summarized in Table 5.5. Under average (50 percent

Device:	Estimated Sweep Width (Miles)	(Km)
Red/orange balloon	1/2	1
Red 2-star flare	1/2	1
Orange flight suit	1/2	1
Day/night flare	1/2	1
Red pengun flare	3/4	1.5
Red reflective paulin	2	4
Tracer bullets	2	4
Green dye marker[1]	2	4
White parachute	5	10
Orange smoke[2]	5	10
Sun signal mirror	5	10

[1]Greatly reduced in heavy seas.

[2]Greatly reduced in high winds.

(a) Daylight Detection Aids Visual Sweep Width

Device:	Estimated Sweep Width (Miles)	(Km)
Electric floating lantern	1	2
Hand flashlight	3	6
Tracer bullets	4	8
Red Very signals	8	16
Aircraft marine markers	8	16
Day/night flare	8	16
Strobe lifejacket light	10	20
Red pengun flare	10	20
Red 2-star flare	10	20

(b) Darkness Detectin Aids

Table 5.1 - Typical Sweep Widths for Various Detection Aids (USCG, 1973)

Target	Meteorological Visibility (km)					
	2	6	10	20	30	40
	Sweep Widths (km)					
15m Boat	1	7	8.4	13	17	17.2
7m Boat	1	5	5.4	7.8	10.4	10.6
Liferaft	1	2	2.8	3.6	3.8	4.0
Person in water	0.1	0.2	0.3	0.4	0.4	0.4

Table 5.2 - Estimated Sweepwidths for Visual Search (Uncorrected for Sea State and Cloud Cover; for an Observer at Sea Level)

Target	Wind (knots) 0	10	15	20	25	30	40	50	60
Rafts	0.8	1.0	0.9	0.7	0.5	0.2	0.1	-	-
Boats	0.9	1.0	1.1	1.0	0.9	0.7	0.2	-	-
Ships	1.1	1.0	1.0	0.9	0.8	0.7	0.5	0.2	-
Dye Markers	0.9	1.0	1.0	0.9	0.6	0.4	0.2	-	-
Smoke	0.6	1.0	0.6	0.6	0.4	0.2	0.1	-	-

Table 5.3 - "Whitecap" Correction Factor, "f_w"
(USCG, 1973)

	Percentage Cloud Cover 0	10	20	30	40	50	60	70	80	90	100
Cloud Cover Factor	1.1	1.1	1.1	1.0	1.0	1.0	1.0	0.9	0.9	0.8	0.7

Table 5.4 - Lighting Correction Factor, "f_1"
(USCG, 1973)

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exceedance) conditions visual search sweep widths are unaffected by prevailing environmental conditions during the summer months and, for the larger targets, during the winter months. However, sweep widths for small targets under winter conditions can be reduced by 30 percent.

The effectiveness of visual search for the same targets under severe (25 percent exceedance) conditions suggests sweep widths off Nova Scotia and over the Grand Banks will be very much reduced by the presence of fog during the late spring and early summer months. During the winter months visibility will also be reduced and winds will be stronger, resulting in sweep width reductions of 10 percent for larger targets and 50 percent for the smaller targets. Results for the northern areas cannot be relied on due to the paucity of data.

Visual searches will be further hampered by limited daylight during the winter months - ranging from eight hours in the south to zero in the north. In summer the number of hours of daylight increases to 14 in the south and 24 in the north. However, under clear weather conditions sweep geometry will often be modified by low sun angles (Figure 5.2).

The above visual search sweep widths have been derived from tables in the current SAR Manual which are based on World War II data and take into account only five factors: height of the lookout, target size, visibility, wind, and cloud cover. Between 1978 and 1981 the USCG undertook seven experiments as part of a re-evaluation of the visual detection guidelines in the SAR manual (Edwards, et al, 1981). In the course of the experiments, the USCG used 25, 29, and 64 m cutters and 12.5 and 13 m utility boats as search vessels. The targets were 5 and 12.5 m boats,

AREA	Target	WINTER Vis. (km)	WINTER W_u (km)	WINTER f_w	WINTER Sweep width (km)	SUMMER Vis. (km)	SUMMER W_u (km)	SUMMER f_w	SUMMER Sweep width (km)
50% exceedence (average conditions)									
All areas	15m boat	10	8.4	1.0	8.4	10	8.4	1.0	8.4
	7m boat		5.4	0.8	4.3		5.4	1.0	5.4
	Liferaft		2.8	0.7	2.0		2.8	1.0	2.8
	PIW		0.3	?	0.3		0.3	1.0	0.3
25% exceedence (severe conditions)									
Georges Bank, Sable & Banquereau	15m boat	10	8.4	0.9	7.6		1	1.0	1
	7m boat		5.4	0.7	3.8		1	1.0	1
	Liferaft		2.8	0.5	1.4		1	0.9	1
	PIW		0.3	?	0.3		1	?	1
Gulf Magdalen	15m boat	5-10	7.0	0.9	6.3	10	Same as average (50%) winter conditions.		
	7m boat		5.0	0.7	3.5				
	Liferaft		2.0	0.5	1.0				
	PIW		0.2	?	0.2				
SE and N Grand Banks	15m boat	5-10	Same as Gulf Magdalen winter conditions			1	Same as Georges Bank, etc. summer conditions		
	7m boat								
	liferaft								
	PIW								
Belle Isle Banks NW Labrador, Davis Strait	15m boat	3-10	7.0	1.0	7.0	3-10	7.0	1.0	7.0
	7m boat		5.0	0.8	4.0		5.0	1.0	5.0
	Liferaft		2.0	0.7	1.4		2.0	0.9	1.8
	PIW		0.2	?	0.2		0.2	?	0.2

Table 5.5 - Estimated Visual Search Sweep widths for Standard Targets Under Average (50% Exceedence) and Severe (25% Exceedence) Environmental Conditions for Typical Forecast Areas

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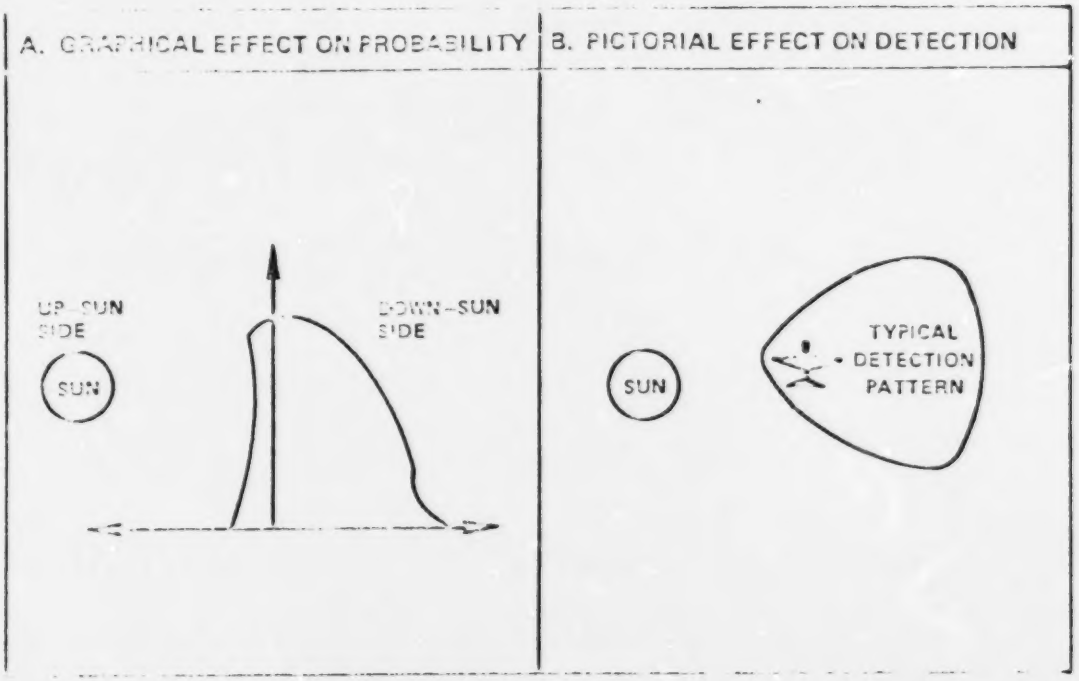

Figure 5.2 - Effect Of Orientation To Sun On Sweep Geometry
(USCG, 1973)

liferafts, and manequins to simulate persons in the water. The following factors were taken into account in calculating sweep widths:

- search vessel characteristics (number and height of lookouts, speed and navigation capabilities),
- target characteristics (size, shape, and colour),
- visibility,
- search speed,
- time on task,
- wind speed and swell height,
- sun elevation and relative bearing, and
- cloud cover.

The conclusions reached at the end of the experiments were:

- The larger cutters with the most lookouts and better navigation aids permitted larger sweep widths than the smaller utility boats (This factor is not considered in the current SAR Manual).
- The SAR Manual overstates the influence of visibility on sweep width for small targets, especially when visibility is greater than 20 km.
- The speed of the search vessel has no effect on sweep width.
- Sweep widths should decrease with increased time on task due to lookout fatigue. Other human related factors include visual acuity, training, experience and motivation levels, and lookout position. None of these factors are presently taken into account.
- Sweep widths were found to decrease steadily with increasing wind and swell. The SAR Manual suggests sweep widths will increase as the wind increases from 0 to 15 knots.

- Sun angle has no great effect on sweep width.
- Cloud cover has less effect than predicted in the SAR Manual.

Applying the results of these experiments to a search for a 16 foot (5 m) boat or liferaft under average winter conditions on the Grand Banks (15 knot wind, visibility 10 km), the sweep width for a cutter, when the targets are a white boat or an orange canopied raft, is 3.3 km and for a utility boat, 3.1 km. For a blue boat or raft with no canopy, the sweep width for both search vessels is 2.4 km, and for a black raft with no canopy, it is 2.2 km in both cases. When the time on search is greater than four hours, indications are that sweep widths should be halved. The current SAR Manual based on a 7 m target, and the same visibility and wind speed gives a single sweep width of 4.3 km.

A further factor that visual sweep width calculations do not appear to take into account is the relationship between the ship's course and the wave direection. For instance, a low-lying target (freeboard less than wave height) will be visible to a searcher looking across the wave crests only a fraction of the time that it would be visible to one looking parallel to the wave crests. To assess the implications of this factor, NORDCO has developed a simple look-out target intervisibility model which takes into account the height of the lookout, the free board of the target, the range to the target, and the height and period (or wavelength) of the waves. An example of the output is given in Figure 5.3. The lookout aboard the ship is in the centre of the diagram and 10 m above the sea surface. The wave crests are moving towards the observer from the top or bottom of the page, such that the crests are parallel to the box in the centre of the diagram. The freeboard of the target is 0.3 m

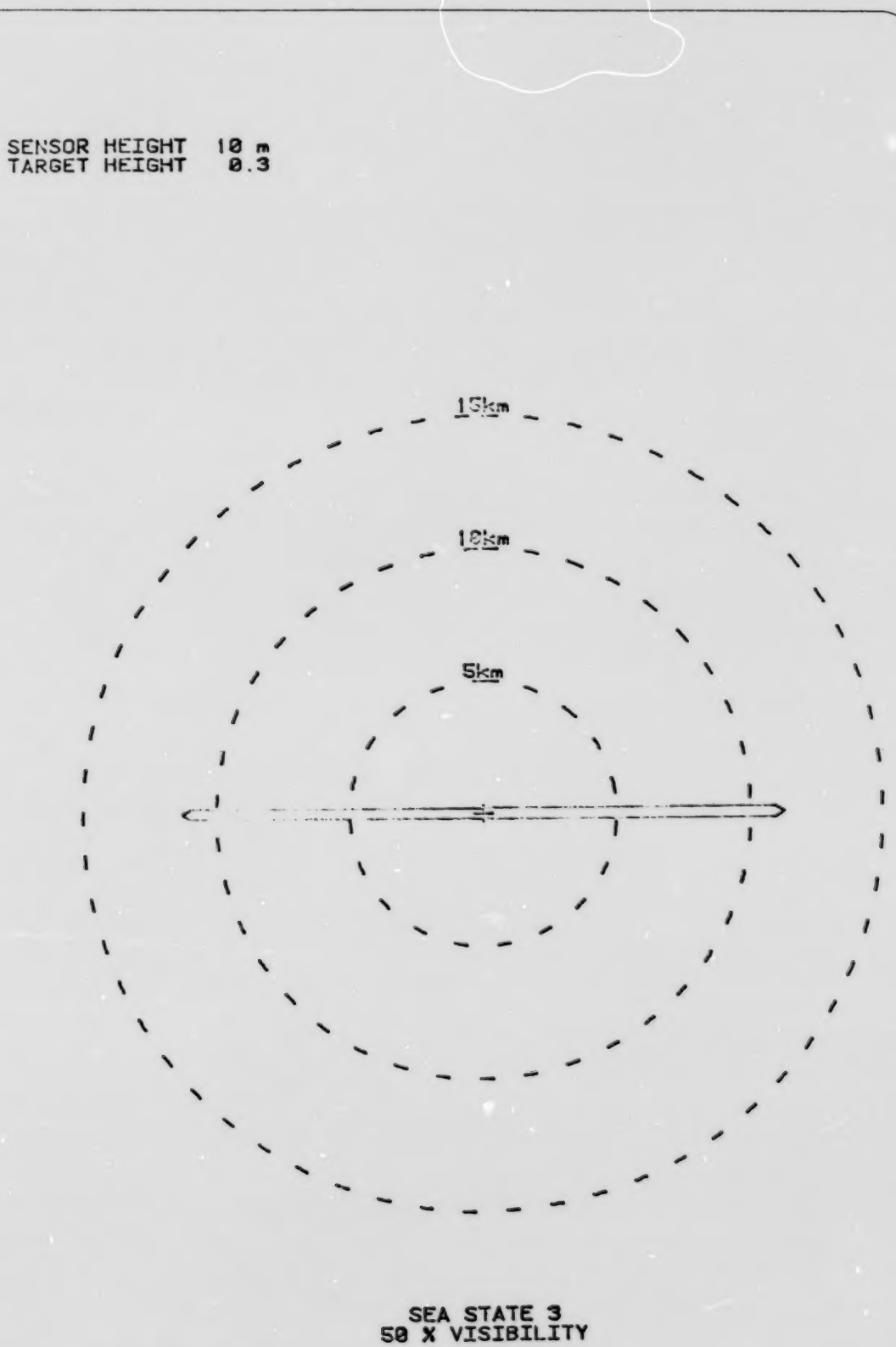

Figure 5.3- Example Of Intervisibility Model Output

(roughly equivalent to a person in the water) and, at sea state 3, the waves are 1.2 m high. Within the box, the target is visible more than 50% of the time, and outside the box, less than 50% of the time. Thus, this simple model, that does not take into account target colour or the impact on detectability of having a target outlined against a sky background, indicates that the time available for a lookout searching across the wave crests to detect a target is very much less than for one searching parallel to the crests.

The general conclusion to be drawn from this review of sweep width calculations is that many more factors must be taken into account than are considered in the present SAR Manual tables. If it can be shown that information on the additional factors is likely to be available to a search planner, a computer model will be required to assist the planner in optimising his sweep width calculations.

5.3 Radar Sweep Widths

No comprehensive, experimentally derived or theoretically based tables for the calculation of sweep widths for radar were found in the course of the literature search. However, the USCG SAR experiments described in Section 4.4 did include an analysis of the performance of an AN/SPS-64(V) radar aboard a 25 m cutter and an AN/SPS-66 radar aboard a 12 m utility boat. The conclusions regarding the sweep widths for the two installations can be summarized as follows:

- The more powerful AN/SPS-64(V) radar with the higher antenna mount gave sweep widths in the order of 9 to 12 km for small boats and liferafts equipped with reflectors under sea states 0 to 1, and 3 to 5 km under sea state 2 conditions. The AN/SPS-66 radar

aboard the smaller vessel gave sweep widths for the same targets which were approximately 50% and 20% of those for the larger vessel under sea states 0 to 1 and sea state 2, respectively.

- In the absence of radar reflectors on the targets, the above sweep widths are reduced by 60% under calm conditions for the AN/SPS-64(V) and 50% for the AN/SPS-66 radar. In sea state 2, the sweep width for the An/SPS-64(V) is halved in the absence of reflectors on the targets, and the AN/SPS-66 cannot be relied on to detect the targets at all.

- In general, radar sweep widths decrease rapidly with increasing sea state.

The USCG experiments did not encompass typical Canadian environmental conditions. Therefore, NORDCO's radar performance modelling program was used to calculate the probability of detection of the targets used in the USCG experiments. The results, which are summarized in Table 5.6, must be treated with caution. The USCG sweep widths are based on experimentally derived cummulative propability of detection data, whereas the NORDCO sweep widths represent the 50% detection range based on instantaneous propability of detection curves. Figure 5.4 illustrates a typical model result for a small boat target with a radar reflector using the AN/SPS-64(V) radar aboard an 25 m WPB in a sea state 2. At the 50% probability of detection level the range is 3.2 km, which is doubled (for both sides of the search vessel) to give a sweep width of 6.4 km. There are two other differences between the two sets of results: the experimental data reflects variations in operator skill, and naturally includes the lookout-target inter-visibility factor discussed earlier in the context of visual search.

Radar	Target (small boat/liferaft)	Sweep Widths (km) SS2	SS3	SS4	SS5
50% Probability of Detection					
AN/SPS-64(V) (25 m WPB)	With reflector	6.4 (5.0)[1]	6.3	2.4	0.6
	No reflector	4.4[2](3.3)	-	-	-
AN/SPS-66 (12.54m UTB)	With reflector	3.1 (1.1)	0.3	-	-
	No reflector	- (-)	-	-	-
25% Probability of Detection					
AN/SPS-64(V) (25 m WPB)	With reflector	7.0	6.9	4.1	2.5
	No reflector	4.7	-	-	-
AN/SPS-66 (12.5 m UTB)	With reflector	3.5	3.4	0.9	0.3
	No reflector	-	-	-	-

Notes: 1) (xx) USCG experimentally derived sweep widths for sea state 2

2) 40 - 50% probability of detection

Table 5.6. - Approximate Sweep Widths Calculated Using the NORDCO Model (50% and 25% detection probabilities under sea states 2 to 5 for the AN/SPS-64(V) and AN/SPS-66 radars used in the USCG SAR tests off Florida and New York under sea states 0 to 2)

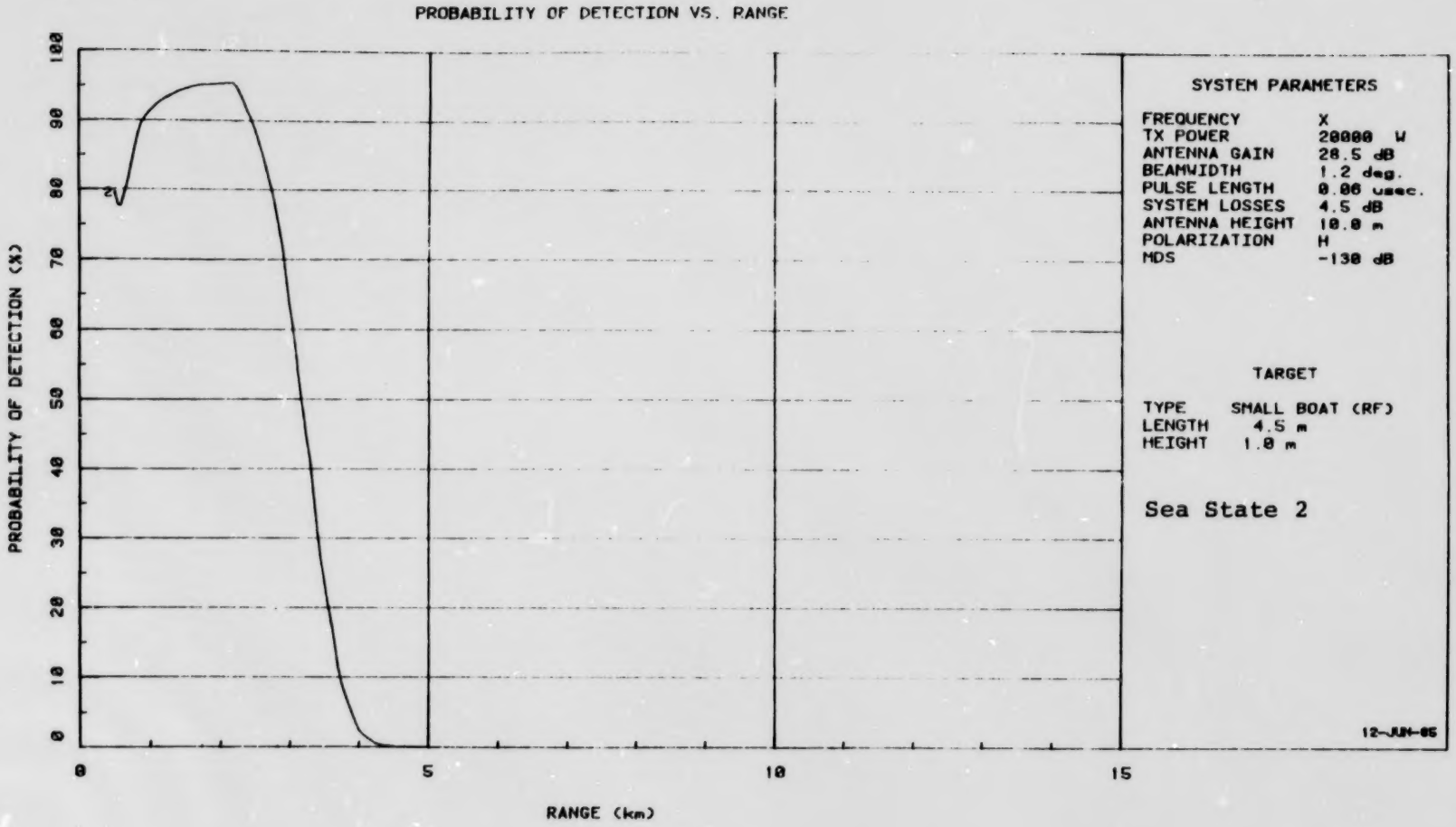

Figure 5.4 Instantaneous Probability of Detection Versus Range(for a small boat with a radar reflector using the AN/SPS-64(V) radar tested by the USCG).

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In the NORDCO model, the first factor is simulated by repeat looks equivalent to an operator noting a radar "blip" on successive scans, and the second factor has not yet been included in the calculations. Despite these differences, the NORDCO model gives some idea of the degradation in radar performance for detection of a particular target that might be expected with increasing sea states.

Radar cross section information is required to calculate radar sweep widths for the various standard targets identified in Section 2 of this report. Unfortunately, these are only available for small boats (or liferafts) so comparisons with visual sweep widths are only possible for the 7 m boat and liferaft categories. USCG experimental data can be used with some confidence for sea states 0 to 2, but for typical Canadian conditions (sea states 3 to 5) the NORDCO model results have to be used. For the USCG data it can be concluded that radar sweep widths will be at least as great as those for visual search in daylight and very much greater when visibilitly is reduced at night and in fog or rain. However, the NORDCO results (Table 5.6) for higher sea states typical of the Canadian offshore, indicate visual sweep widths are generally greater than those for radar when visibility is good (at least 10 km). Again, radar will be better than visual search in darkness or in fog.

A number of conditions have to be placed on the above conclusions. The radar sweep widths have only been calculated for a 4.5 m boat with a 1 m freeboard, and the NORDCO model does not yet include precipitation clutter or a lookout-target inter-visibility factor. Further work is required to establish the radar cross-sections for 15 m boats and persons in the water to complete the comparison between visual and radar sweep widths.

5.4 Sweep Widths for Other Sensors

Table 5.7 summarizes the information available on the performmance of a FLIR system, LLLTV, and acoustic target detection systems. No sweep width information is available so range data has been multiplied by two for both sides of the search vessel - the results can only be treated as an indication of how such sensors might perform in a SAR situation. For instance, the FLIR system used in the USCG tests was helicopter rather than ship mounted, and the Naval Ocean Systems report contained no information on the environmental conditions during the tests. The same lack of environmental information is true of the Naval Ocean Systems and the CCG LLLTV tests. Also, the latter were carried out on a hovercraft and it was noted that spray degraded the results. In the acoustic tests carried out by the Bedford Institute of Oceanography, (McKeown, 1985) the pingers or transducers were attached to a variety of floating bodies with no intent to simulate a SAR situation. However, these last experiments were apparently carried out in a sea state of approximately 3 and the theoretical modeling suggests this technique for detecting SAR targets may be less dependent on above surface environmental conditions than any of the others, including visual search.

Despite the lack of quantitative information, the following general conclusions can be drawn:

- A FLIR system may be as good as or better than radar at night for low sea states and good visibility.

- Active LLLTV is far preferable to a passive system. However, infrared (except for resolution) is probably better than both TV systems.

Instrument	Target	Range x 2 (km)		
Infrared		SS 0-1		SS 2
FLIR (helicopter mounted)	4.5-6.0 m boat	3.4		2.2
	4-7 man liferaft	3.0		2.2
	PIW	1.2		0.8
FLIR (Naval Ocean Systems, 1977)	Small boat		4-4.8	
	Liferaft		4-4.8	
	Vertical log		4.0	
Low Light Level TV		Passive		Active
LLLTV (Naval Ocean Systems, 1977)	Row boat	0.6		>7.2
	Rubber boat	1.8		>7.2
	Vertical log	2.2		>7.2
LLLTV (CCG hovercraft VISTAR test, 1985)	5 m boat	0.8		0.8
	Vertical log	1.6		1.6
Acoustic				
Active system (McKeown, 1985)	20-50 kHz Pinger or transponder		2-4	

Table 5.7 Approximate Sweep Widths Based on Available Detection Range Data (multiplied by two for both sides of the search vessel - this summary must be treated with great caution - see text for details)

- Acoustic systems may be the least sensitive to prevailing above surface environmental conditions and, provided the target carries a pinger or transducer, detection capabilities are independent of target size, shape, colour, etc.

6.0 PRELIMINARY EXPERIMENT PLAN FOR SHIPBORNE SAR SENSOR EVALUATION

6.1 Objectives

Earlier USCG experiments to establish sweep widths for visual and remote sensing detection of targets were carried out under less severe environmental conditions than those typical off the East Coast of Canada. However, the USCG experimental and statistical analysis procedures do provide a valid basis for an experiment to be carried out under Canadian conditions. Discussions with CCG officials in the Newfoundland Region suggest Placentia Bay on the south coast of the Island would be a suitable experiment site and would permit use of the SAR vessel "Jackman" and the Burin lifeboat over a ten day target detection program without serious disruption of their operational program.

The objectives of tests in Placentia Bay would be to experimentally determine the instantaneous and cumulative probability for the visual and radar detection of a variety of targets under different environmental conditions. The data set would be used to calculate the appropriate sweep widths for visual and radar searches using the Jackman and the Burin lifeboat.

There is a possibility that manufacturers of FLIR and LLLTV systems would be willing to provide equipment to be evaluated as part of a CCG SAR target detection program. Also, it may be possible to borrow an acoustic system from the Bedford Institute of Oceanography to compare this mode of target detection with conventional visual methods and other remote sensing techniques. At present, these options

are regarded as secondary to the determination of visual and radar sweep widths for the "Jackman" and the Burin lifeboat.

6.2 Test Site

The recommended test site is on Merasheen Bank near the head of Placentia Bay (Figure 6.1). The Bank is between 10 and 20m deep, 20 km long in a NNE-SSW direction and about 2 km wide. All targets would be located on the Bank to minimize mooring costs. The centre of the test site is about 30 km from Argentia (the Jackman's normal base) and 60 km from Burin. The recommended shore base is Argentia.

6.3 Environmental Conditions

Environmental conditions in February and March for Placentia Bay are summarized in Table 6.1. Waves will be fetch limited for winds from the most common direction, the west, but nevertheless, conditions during a ten day test program should be more severe than those encountered during the USCG tests. During the actual tests wind speed and direction, wave (sea and swell) height, period and direction, visibility (rain, snow, fog and light conditions), and sea and air temperature (if an infrared system is included in the tests) will be recorded. It is recommended that a waverider buoy be moored in the centre of the area throughout the test program and that CTD measurements be made daily if underwater acoustic detection techniques are used.

6.4 Targets

The USCG targets are listed in Table 6.2. The targets proposed for the Canadian experiments are listed in Table 6.3. As in the USCG tests, all targets should be with and

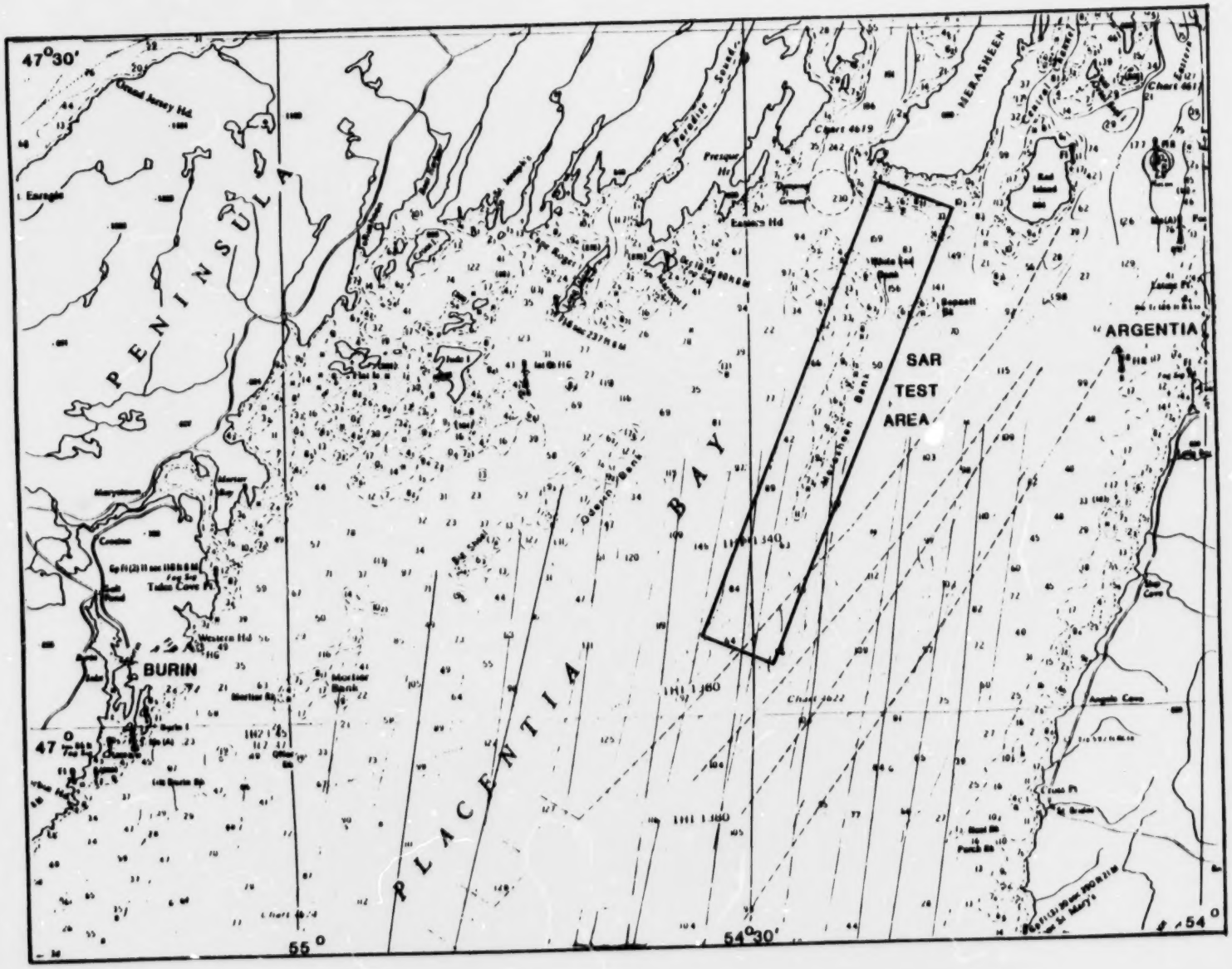

Figure 6.1- Proposed SAR Sensor Test Area

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PARAMETER	FEBRUARY	MARCH
Mean Extreme Max Temperature	+8.8°C	+10.0°C
Mean Daily Maximum	+0.6	+1.8
Mean Daily Temperature	-2.4	-0.7
Mean Daily Minimum	-5.4	-3.3
Mean Extreme Minimum	-12.8	-10.0
PERCENT FREQUENCY PRECIPITATION		
Light rain, showers,drizzle	4	5
Moderate and heavy rain	1	1
Light snow	15	12
Moderate and heavy snow	5	4
Percent Frequency sky obscured	7	7
PERCENT FREQUENCY VISIBILITY		
< 1.0 km	6	7
< 2.0 km	12	
< 4.0 km	16	18
< 10.0 km	26	27
WIND		
Median Wind Speed (Knots)	19	17
Most Frequent Direction	W	W to NW
Mean Combined Wave Height	1 to 1.5 m	1 to 1.5 m
Occurrence of Pack Ice	Nil	Nil

Table 6.1 - Environmental Conditions of Merasheen Bank and Vicinity Placentia Bay During February and March

TARGET DESCRIPTION		
SMALL BOATS	4 to 5 m fiberglass outboard	without reflective equipment
		without reflective equipment; 1.5 m wooden post installed
	5 to 5.5 m fiberglass outboard	with engine
	4 to 5 m fiberglass outboard	with 1.3 m steel post installed
		with steel post and 30 cmm Echomaster radar reflector
		with wooden post and 30 cm Echomaster radar reflector
		with wooden post and 28 m Davis emergency radar reflector
		with wooden post and Radark radar reflector
LIFE RAFTS	7-man non-canopies life raft	without reflective equipment
		without reflective equipment; 1.5 m wooden post installed
		with 1.8 m steel post installed
		with steel post and 30 cm Echomaster radar reflector
		with steel post and Morin gold-screen radar reflector
		with wooden post and 30 cm Echomaster radar reflector
		with wooden post and 28 cm Davis emergency radar reflector
		with wooden post and Radark radar reflector
	4 to 6-man canopied life raft	without reflective equipment
		with Mobay metallized fabric canopy

Table 6.2 - Targets used in USCG SAR Ship Radar Tests (Osmer et al., 1982)

TARGET	DETECTION AIDS
Covered fibreglass lifeboat (8 m)	Radar reflector, lights, (pingers)
Fibreglass capsule	Radar reflector, lights, (pingers)
High speed rescue vessel (Zodiac type)	Radar reflector, lights
Canopied liferaft (rubber)	Radar reflector, lights, (acoustic pinger)
Person in water: Lifejacket Survival suit	Reflective material, lights, (acoustic pingers)

Table 6.3 - Proposed Targets for SAR Day/Night Detection Tests in Placentia Bay (with Contingency for Possible Acoustic and Infrared Tests)

without detection aids. To minimize the cost of the proposed Placentia Bay experiment, it is suggested government equipment be used as far as possible, with the remainder provided by suppliers or borrowed from institutes such as the College of Fisheries and Marine Technology in St. John's. All targets would be deployed by the "Jackman" on as short a mooring as possible to minimize changes in target position with wind and tide.

6.5 Positioning

Two positioning systems should be considered: the LORAN-C carried by both search vessels, and a land based system such as SYLEDIS. LORAN-C lines of position are near perpendicular to each other in the Merasheen Bank area, so accuracies should be in the order of 300 to 500 m in the south, but errors may increase near shore due to land path effects. SYLEDIS provides positions to better than 5 m over ranges up to 75 km, but will cost about $50,000 per month as opposed to LORAN-C's zero cost. The USCG used a Mini-ranger system and reported accuracies of 200 m in their tests, which was presumably adequate. Therefore, SYLEDIS is recommended for Placentia Bay.

The SYLEDIS latitude and longitude of each target would be recorded as it is deployed and the position of the SAR vessel during test runs would be either recorded manually at one or two minute intervals, or by using a minicomputer and plotter (if available) linked to the SYLEDIS receiver.

6.6 Sensors

Visual observers and the SAR vessels' radars will represent the minimal program. Two infrared system manufacturers have expressed an interest in providing their

equipment for evaluation during the tests, and an acoustic pinger tracking system may be available from the Bedford Institute of Oceanography. It is recommended that all extra systems be installed aboard the "Jackman" - accommodation and costs permitting. Operators should be well trained in the use of the sensor employed.

6.7 Detection and Tracking Runs

The sensor operator or visual oberver would have some knowledge of where and when to expect a target during detection runs for Cumulative Probability Detection (CPD) versus range data. For tracking runs used to collect Instantaneous Probability Detection (IPD) data, the visual searcher would note how often and how long he could see the target as a function of its range and bearing as the SAR vessel passes the object and it disappears astern. The radar operator would report when he did and did not observe the target blip on each scan.

The geometry of the proposed test site does not permit use of the "box" track used by the USCG (Figure 6.2), so the track has been modified as in Figure 6.3. At 10 knots it is estimated each run will take about two hours.

6.8 Sweep Width Calculation

CPD and IPD statistics would be derived from the experimental data and USCG procedures would be used to convert these to sweepwidths for the different categories of target, sensor, environmental conditions, etc.

6.9 Schedule and Estimated Levels of Effort

It is estimated 60 mandays will be required between the beginning of October and the end of January to prepare a

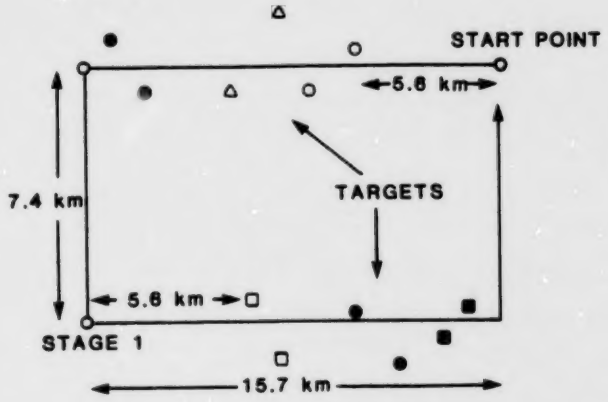

Figure 6.2- USCG Parallel Search Pattern
(Osmer et al,1982)

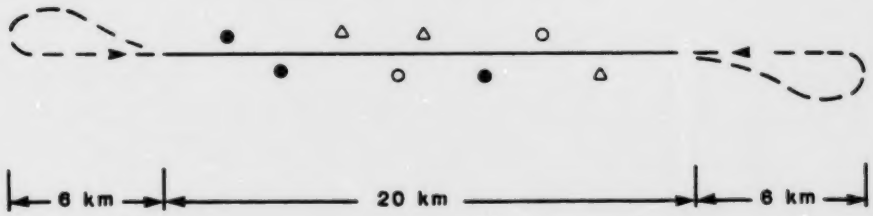

Figure 6.3- Proposed Search Pattern For Placentia Bay

detailed operating plan for the test program (Phase I). The test program itself should take place over a 15 day period in February or March, 1986. The number of mandays will depend on the outcome of the detailed planning exercise, but is presently estimated as 65 mandays (Phase II). Post-experiment data analysis could be completed between April and the end of June, again this will depend on the detailed planning, but is presently estimated to require 60 mandays (Phase III).

These manpower estimates are significantly lower than those reported by the USCG for the 1978 visual detection experiment (Edwards, et al, 1978). The first three USCG tasks (pre-experiment planning and analysis, prototype experiment, and detailed experiment planning) accounted for 116 mandays plus 28 crew mandays, and are equivalent to the proposed Phase I, 60 mandays. The actual USCG experiments lasted 14 days and required 180 mandays plus 144 crew mandays as opposed to the proposed Phase II which includes 5 days shore logistics and 10 days experiments (but no shore base navigation system) and is expected to require 65 mandays, with the crew days undetermined at present. Track recovery after the experiments took the USCG 40 mandays, and analysis of the data, 108 mandays. These are equivalent to the 60 mandays for Phase III. The USCG used 252 hours computer time and 128 hours of desk-top calculator. Computer time for the proposed Canadian experiments is estimated to be 95 hours. The lower estimated effort for the Canadian program is a direct benefit of following the USCG experiment and analysis methodology.

It is recommended that a representative of the USCG, familiar the the earlier SAR target detection experiments participate in the planning of the Canadian experiments and, if possible, in the analysis of the data.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Targets

The key parameters for visual or low light level television detection of targets are their above water shape and size. Colour can be critical in visual detection and the presence of reflective material is a benefit for both visual and LLLTV. For infrared systems, the size of the target is important and the radiated temperature difference between the target and the background sea or sky is critical. For radar detection the size and shape of the target are again important as well as the construction material. The presence of radar reflectors on the target is a definite benefit.

Environmental Conditions

Average Canadian East Coast conditions in the summer are equivalent to Beaufort sea state 2-3 and in the winter to sea states 3-5. Recognizing SAR emergencies can be associated with bad weather the 25 percent exceedance values have also been determined. In the summer sea states will be 3-5 with reduced visibility due to fog, and in the winter the sea states will be 5-6.

Forward Looking Infrared (FLIR) Systems

FLIR systems are reported to show some promise for detection of small objects at sea in sea states up to 3. Potential problems with such systems include the restricted

field of view and possible lack of sufficient thermal contrast between target and background under Canadian offshore conditions, particularly in the presence of fog or rain. Although widely used in the military, there is a lack of information on the performance of such systems for detection of small targets in the open literature. Detection ranges for targets less tha 10 m long have been reported to be 3 to 5 km under good conditions. They perform equally well day or night.

Low Light Level Television (LLLTV)

Active LLLTV systems are preferable to passive systems and both suffer from restricted fields of view. Fog and rain will degrade their performance. There is a general lack of information on their performance in the detection of small targets at sea. Detection ranges are indicated to be similar to those for visual and possible slightly better in light rain or fog. Performance is sensitive to ambient light conditions.

Radar

Under good environmental conditions (sea states less than 2), radar is as good as or better than visual search for small boats, but less effective for extremely small targets such as PIW's. Performance in higher sea states will be degraded, but there is no experimental data to quantify actual ranges for various targets above sea state 2. Military radars employ sophisticated signal processing capabilites and other techniques which significantly improve their higher sea state performance.

Acoustic Systems

Scientific groups routinely use ship mounted or towed sonars to locate equipment carrying a pinger. The evidence of such operations and theoretical modelling suggests a small target, such as a PIW, equipped with a small pinger could be located at distances of at least 1 km virtually independently of sea state and light conditions.

Sweep Widths

The basis for the sweep widths provided in the SAR Manual for visual searches is simplistic. Recent USCG experiments have identified several other factors, such as colour, that should be taken into account (assuming they are known to the search planner). Radar sweep widths are comparable or better than visual under sea states less than 2, but using conventional marine radars, they deteriorate at higher sea states. However, radar is indispensible in fog, rain and at night. There is insufficient information to calculate sweep widths for FLIR, LLLTV, and acoustic systems.

7.2 Recommendations

1) A ten-day target detection experiment should be carried out in Placentia Bay on the south coast of Newfoundland during February or March, 1986. This should be followed by an experiment further offshore later in the year, possibly involving National Defence and the oil industry.

2) The first priority for the experiment program should be to collect the data necessary to calculate sweep widths for visual and radar searches under sea state 3 and 4

conditions. Second priority should be accorded to the assessment of acoustic, FLIR and LLLTV systems.

3) The experiment plan and data analysis procedures should be similar to those used by the USCG in their experimental determination of visual and radar sweep widths for sea states 0 to 2.

4) Target detection models should be developed, validated for the sensors used in the experimental program, and used to extend the results of the experimental program to other sea states and different models of the sensors used in the experiment.

5) The classified literature should be reviewed for information on target detection and tracking using the sensors investigated in this study.

6) Consideration should be given to equipping SAR vessels with more sophisticated radars having significant signal processing capability to improve their ability to detect small targets under adverse environmental conditions.

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APPENDIX A

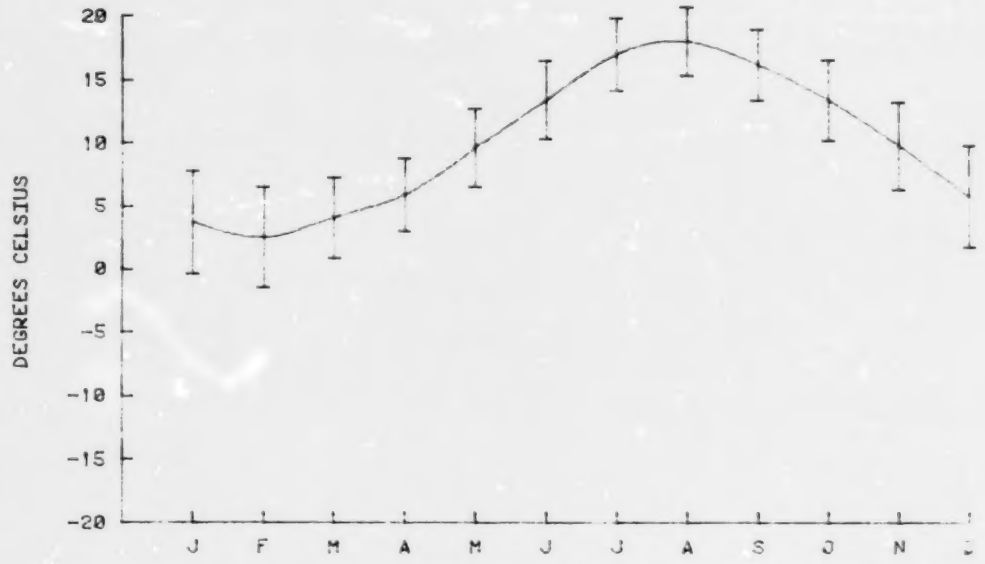
REGIONAL ENVIRONMENTAL DATA

A.1 METEOROLOGICAL, SEA STATE, AND SEA SURFACE TEMPEREATURE DATA

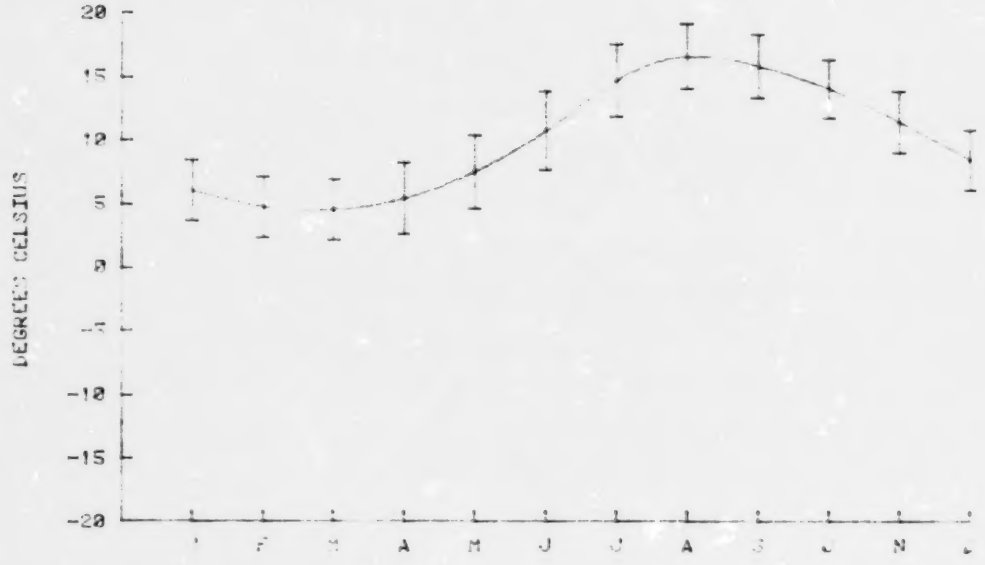
The map on the following page shows the selected areas for which meteorological, sea state, and sea surface temperature statistics have been collected as discussed in Section 3 of this report. For each area, plots of the following climate statistics are shown:

1. Monthly mean air temperature and standard deviation in Celsius degrees
2. Monthly mean sea surface temperature and standard deviation in Celsius degrees
3. Percent frequency of visibility less than 5.4, 2.2, 1.1 and 0.5 nautical miles
4. Percent frequency by month of:
    a. light rain, showers, and drizzle
    b. moderate and heavy rain
    c. light snow
    d. moderate and heavy snow
    e. freezing precipitation (rain and drizzle)
5. Percent exceedence of observed wind speed in knots for each month of the year
6. Percent exceedence of combined wave height in metres for each month of the year. The combined wave height is calculated from the root mean square of the observed wind wave height and the height of the swell waves present.

AES East Coast Marine Forecast Areas –1982
(from Atmospheric Environment Service, 1984)

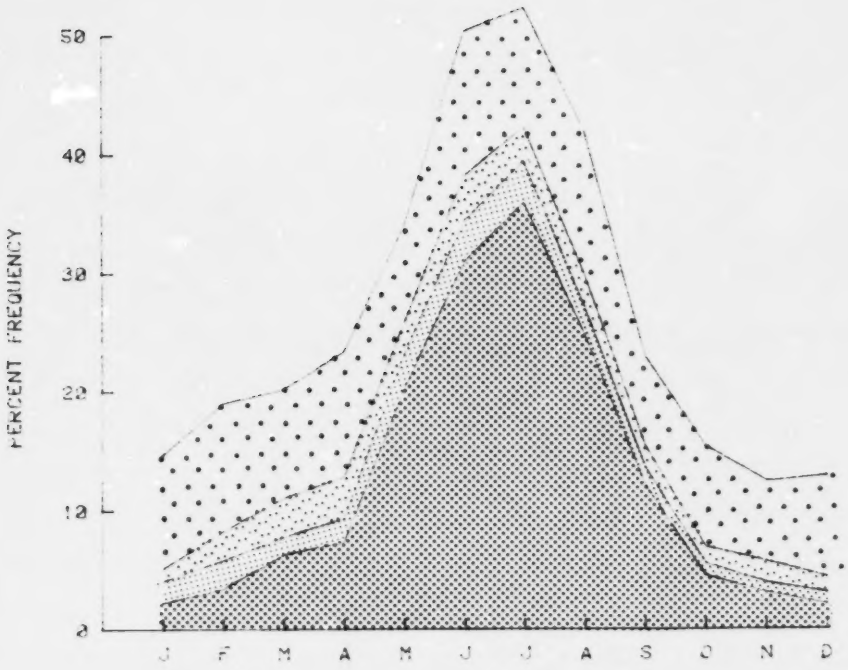


AIR TEMPERATURE



SEA SURFACE TEMPERATURE

GEORGES BANK MARINE FORECAST AREA



PERCENT FREQUENCY OF VISIBILITY
GEORGES BANK MARINE FORECAST AREA

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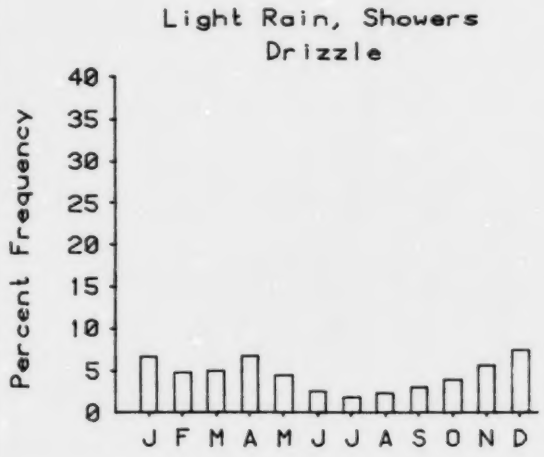
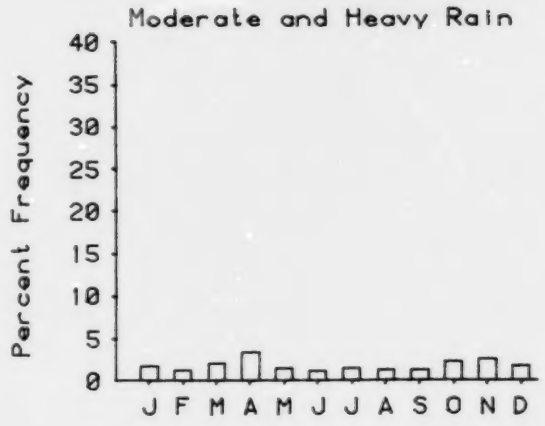
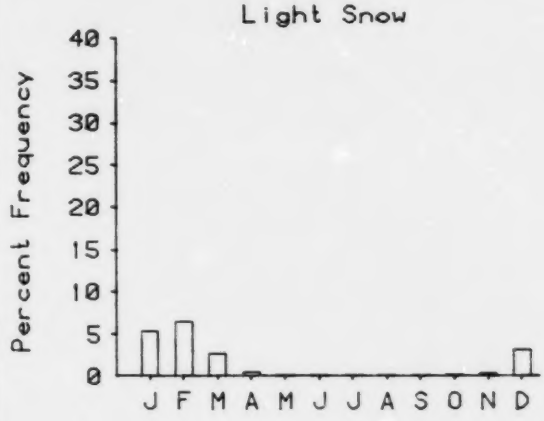
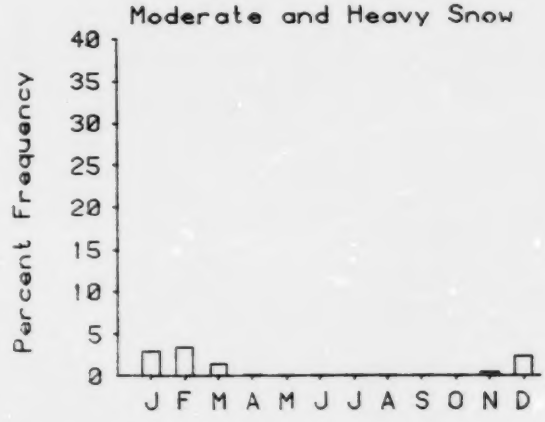
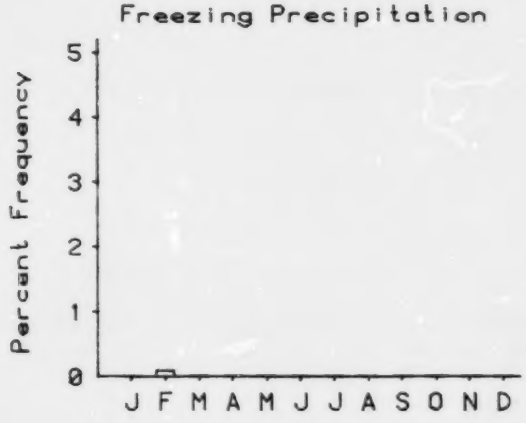
< **2.2** NAUTICAL MILES
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES



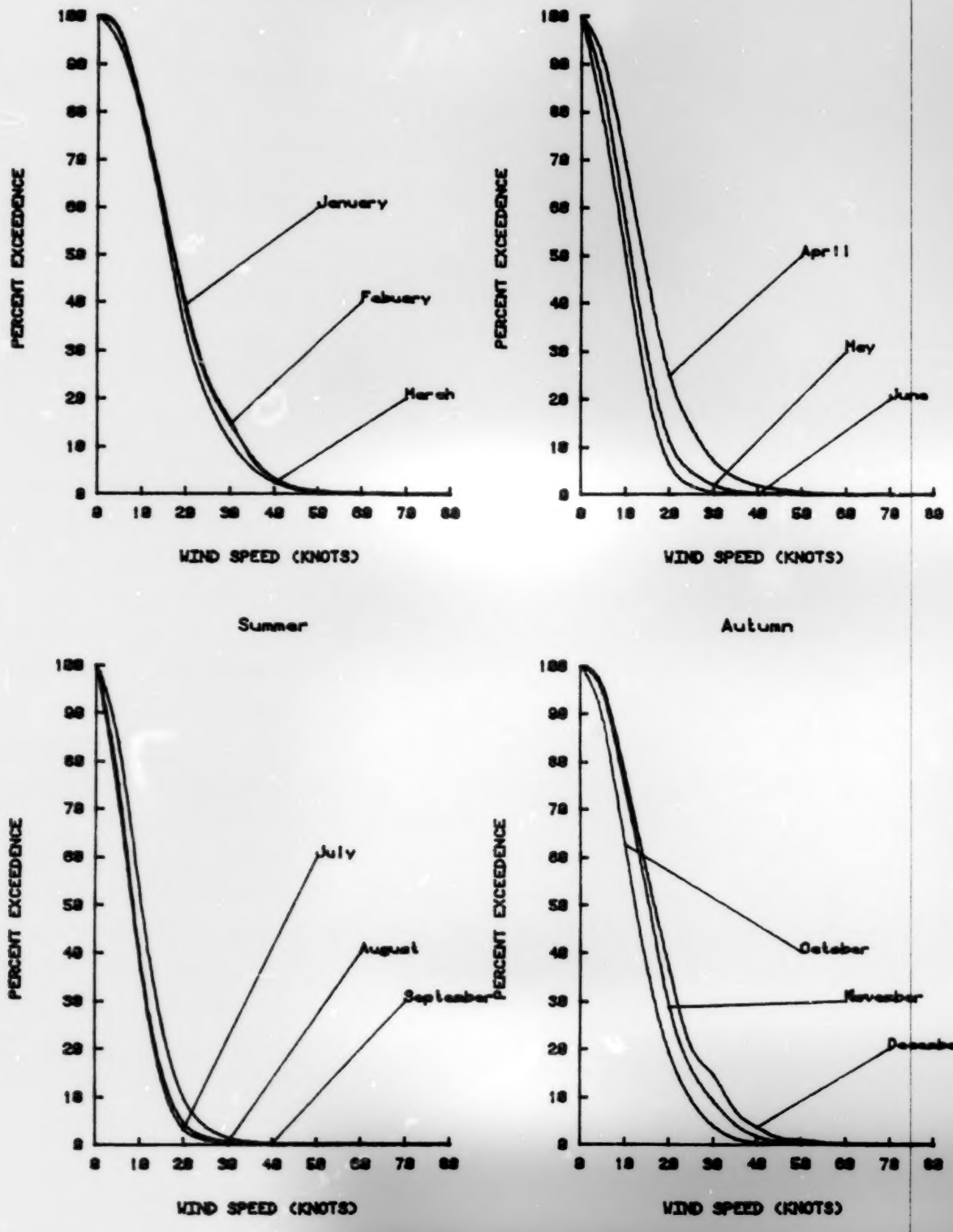




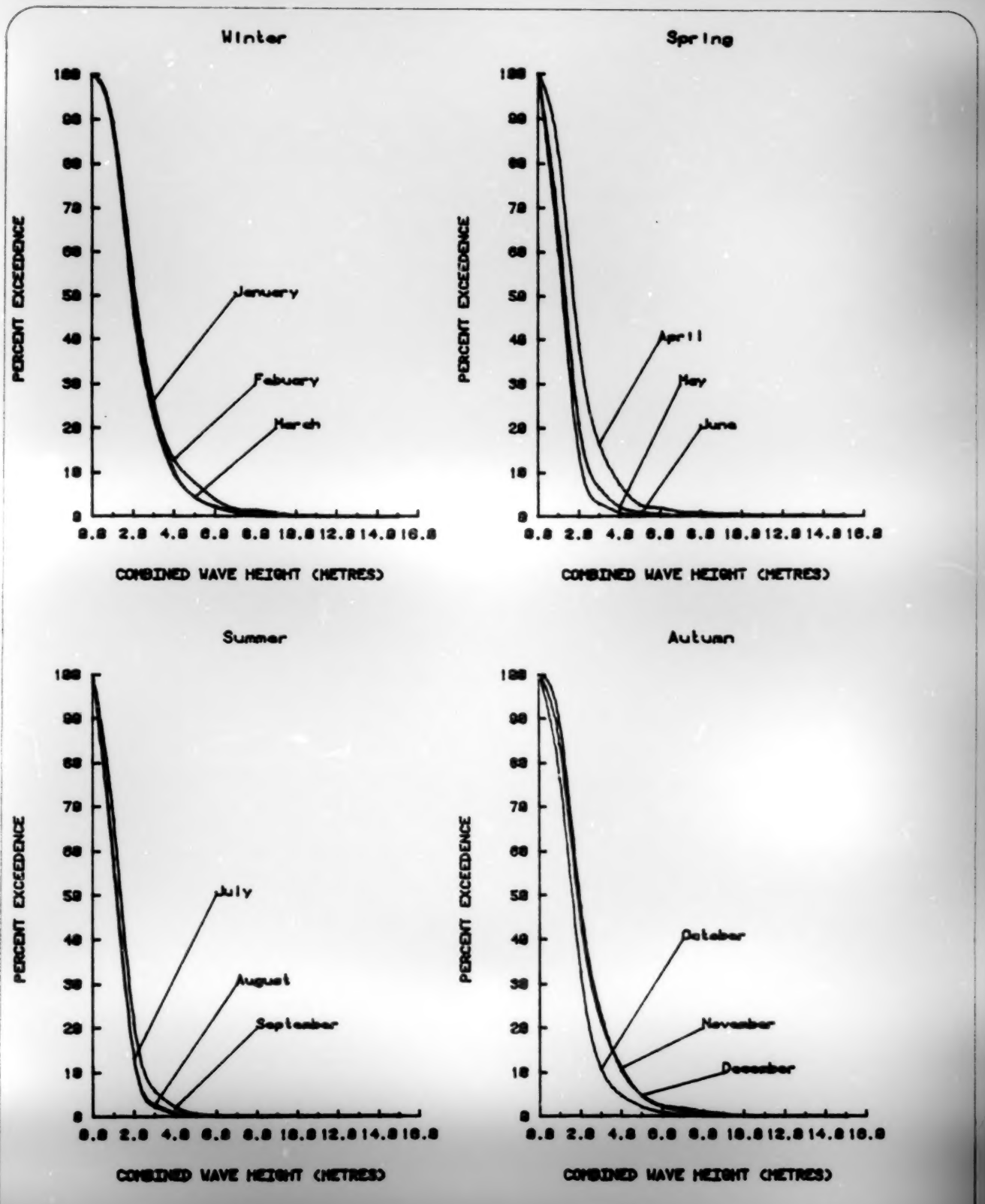




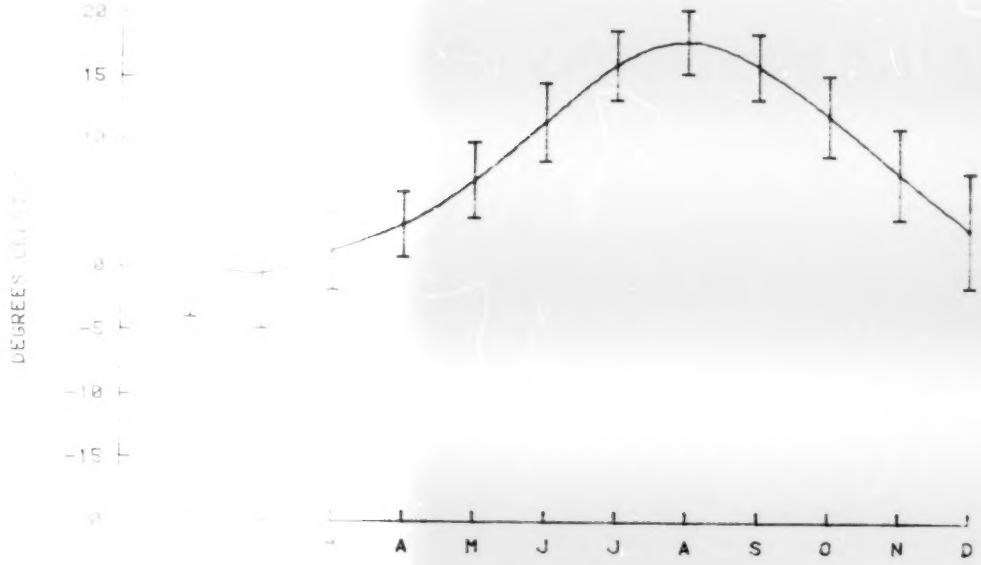
PERCENT FREQUENCY OF PRECIPITATION
GEORGES BANK MARINE FORECAST AREA



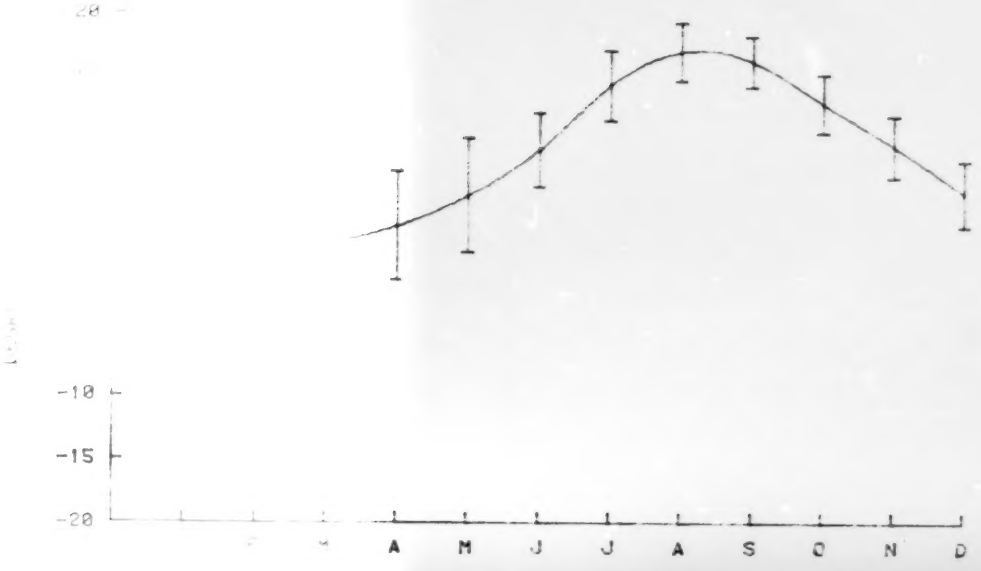
PERCENT EXCEEDENCE OF WIND SPEED
GEORGES BANK MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
GEORGES BANK MARINE FORECAST AREA

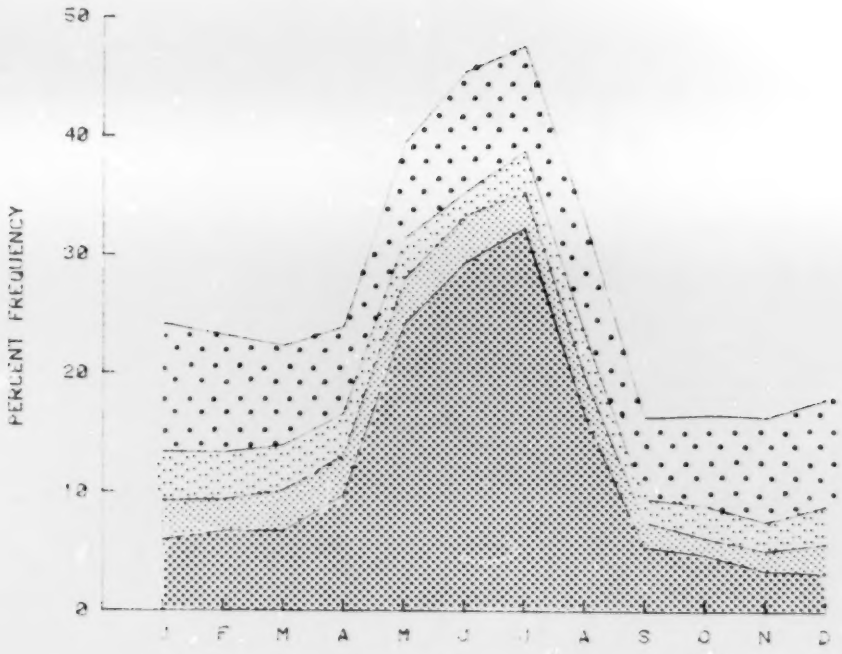


AIR TEMPERATURE



EA SURFACE TEMPERATURE

SABLE MARINE FORECAST AREA



PERCENT FREQUENCY OF VISIBILITY
SABLE MARINE FORECAST AREA

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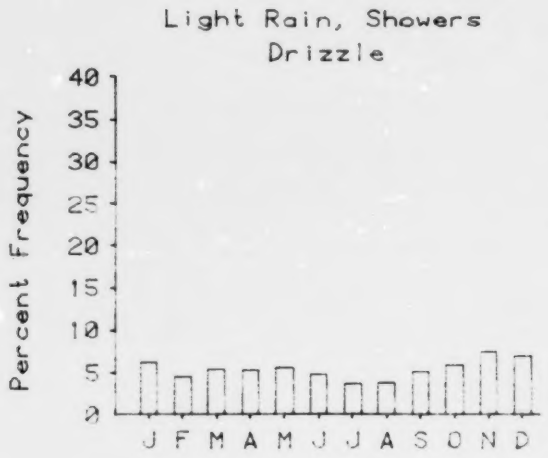
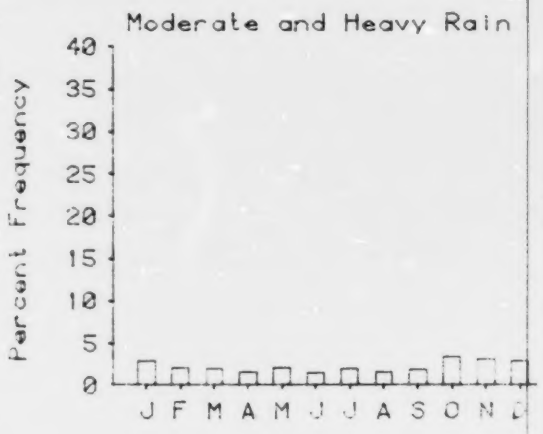
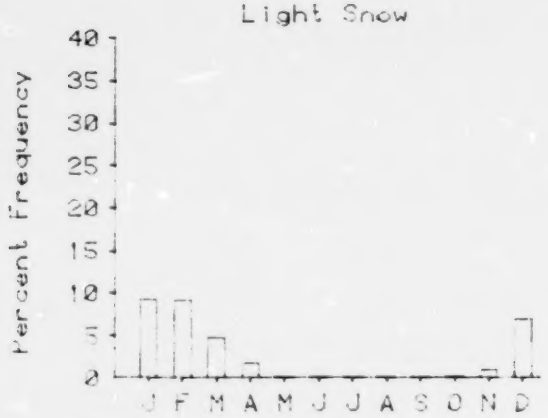
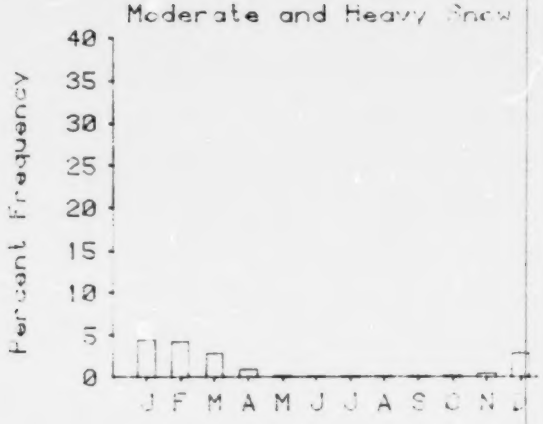
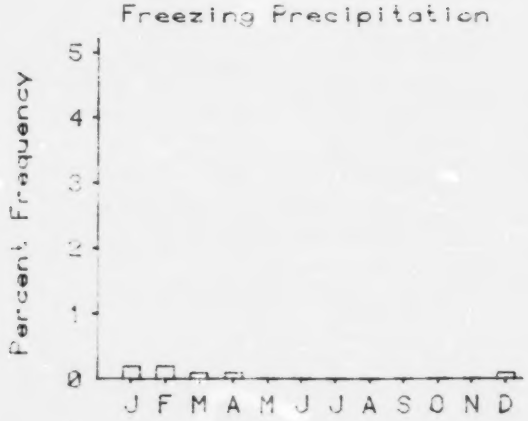
< **2.2** NAUTICAL MILES
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES



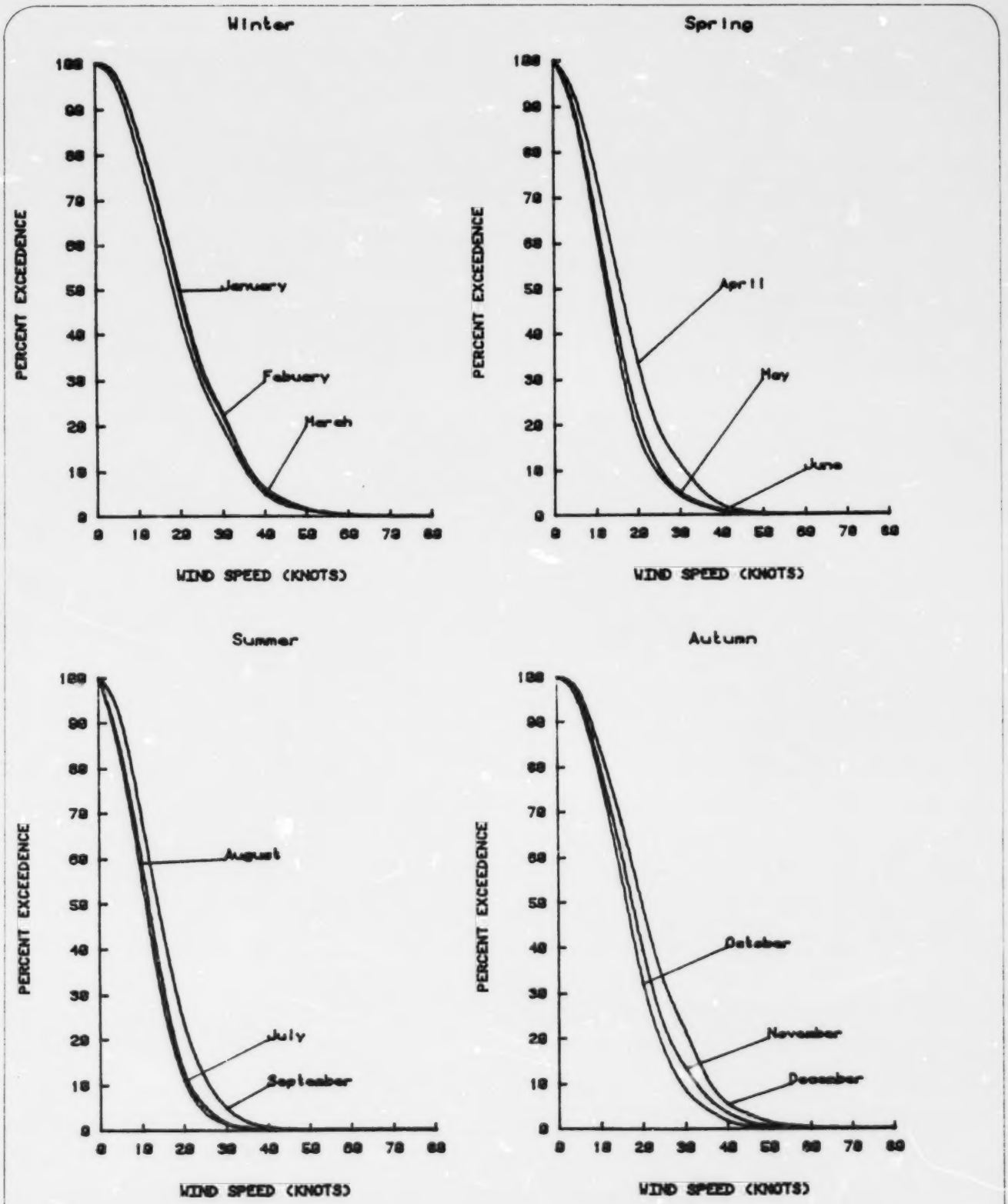




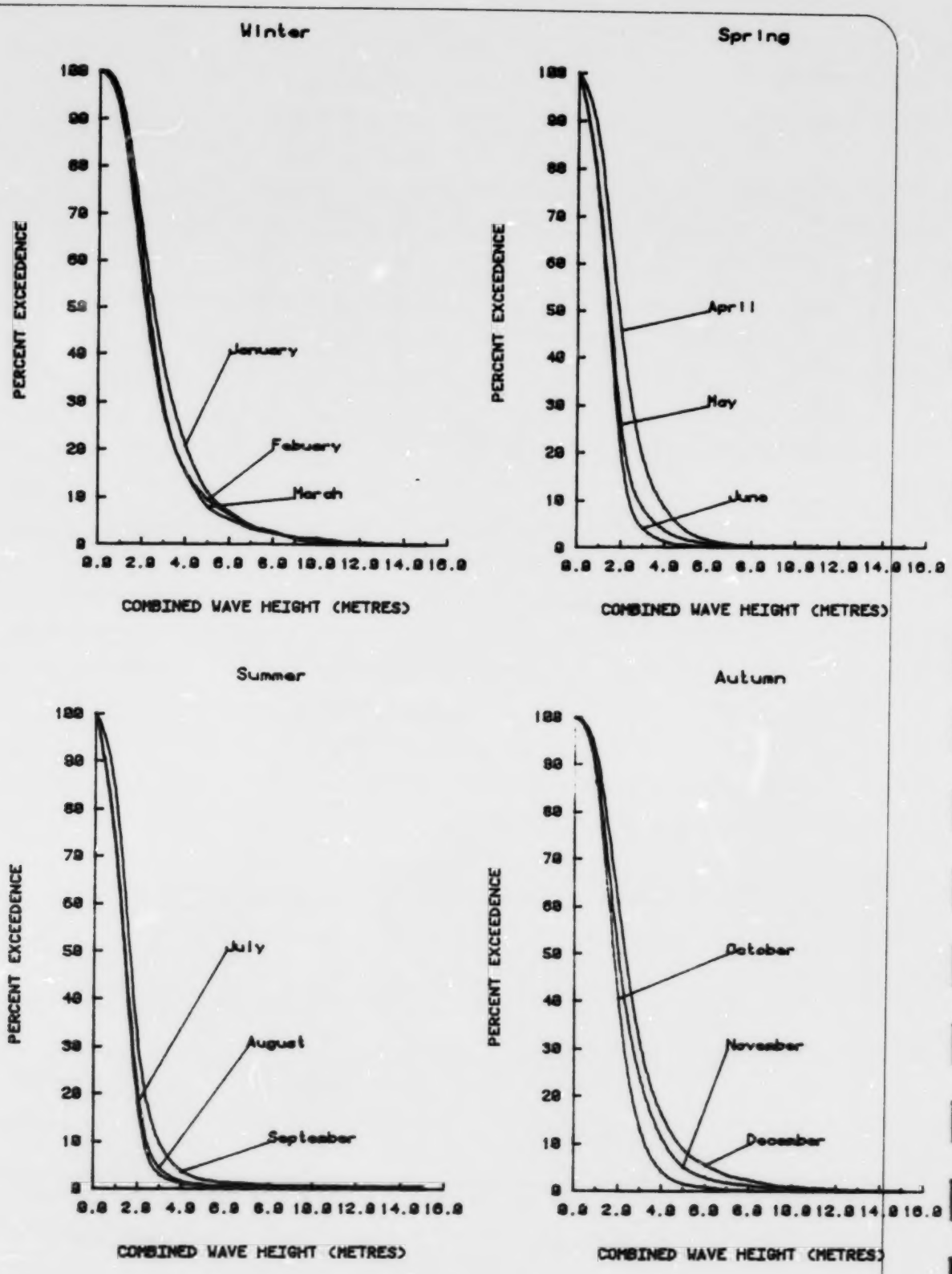




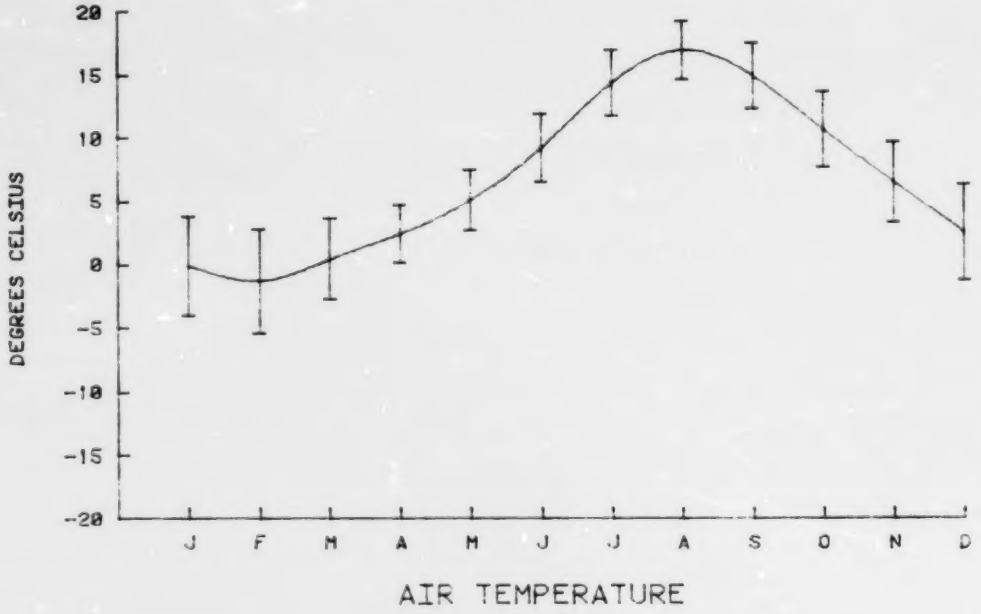
PERCENT FREQUENCY OF PRECIPITATION
SABLE MARINE FORECAST AREA



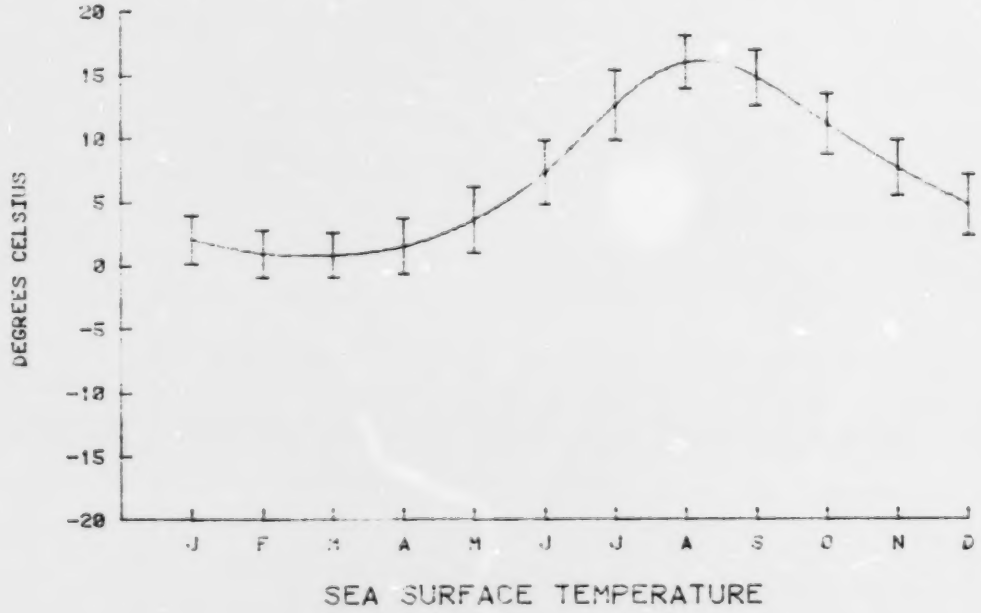
PERCENT EXCEEDENCE OF WIND SPEED
SABLE MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
SABLE MARINE FORECAST AREA

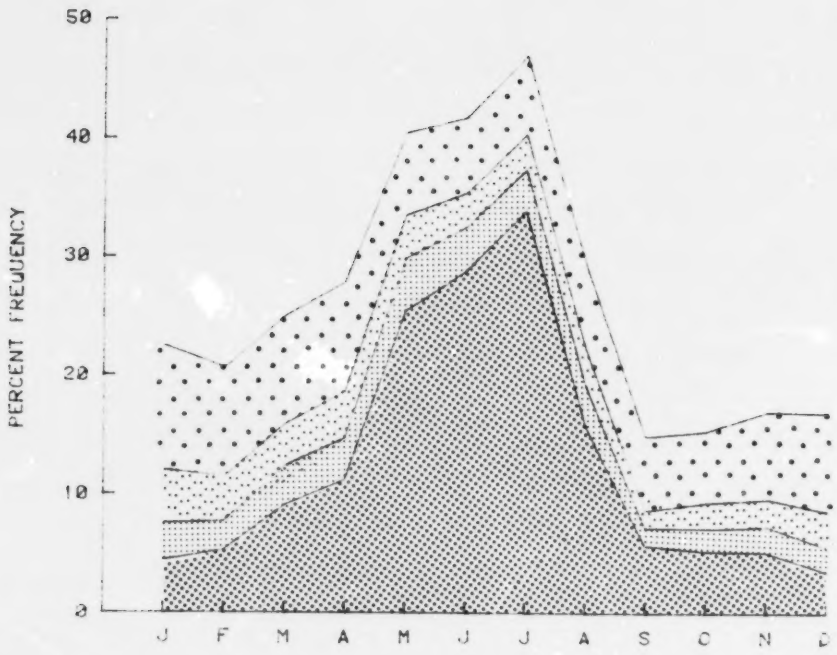


AIR TEMPERATURE



SEA SURFACE TEMPERATURE

BANQUEREAU BANK MARINE FORECAST AREA



PERCENT FREQUENCY OF VISIBILITY
BANQUEREAU BANK MARINE FORECAST AREA

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< **1.1** NAUTICAL MILES
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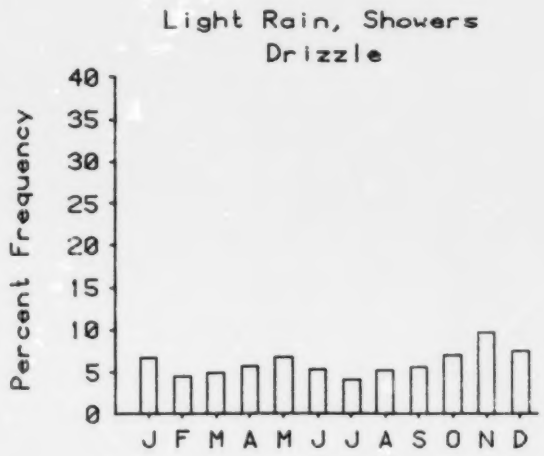

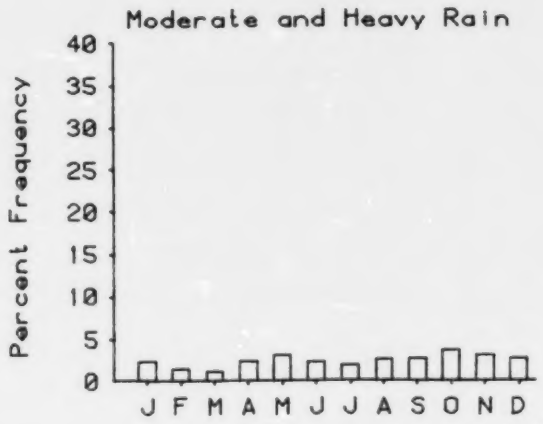

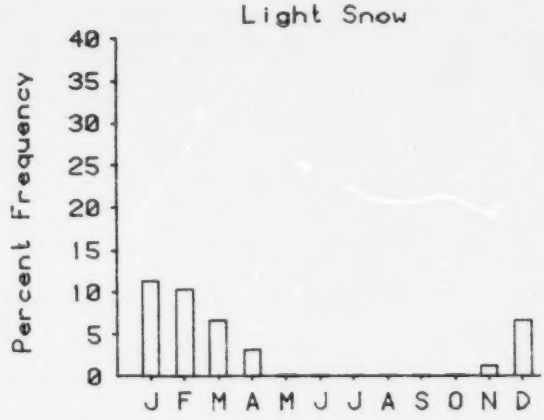

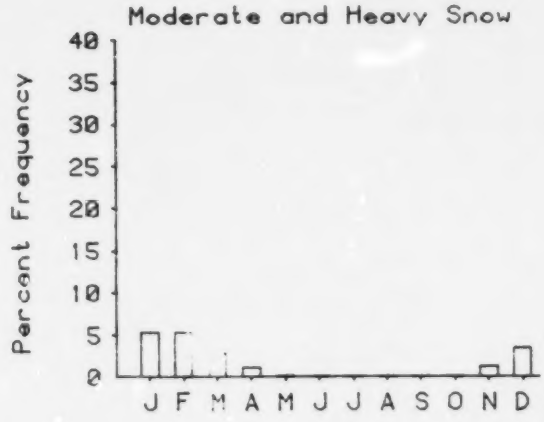

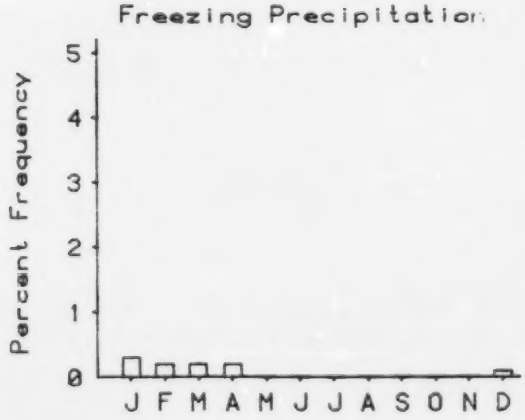

PERCENT FREQUENCY OF PRECIPITATION
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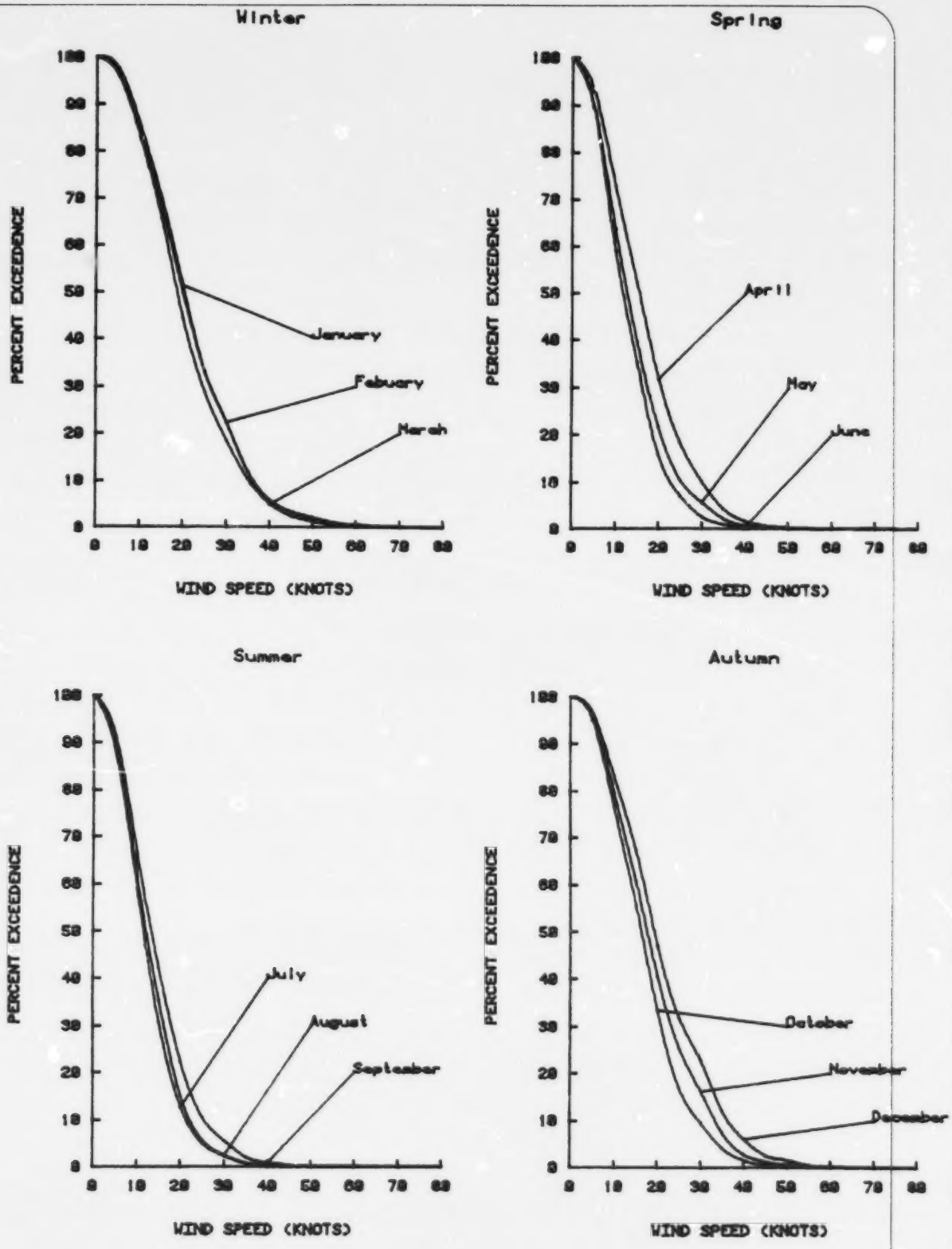
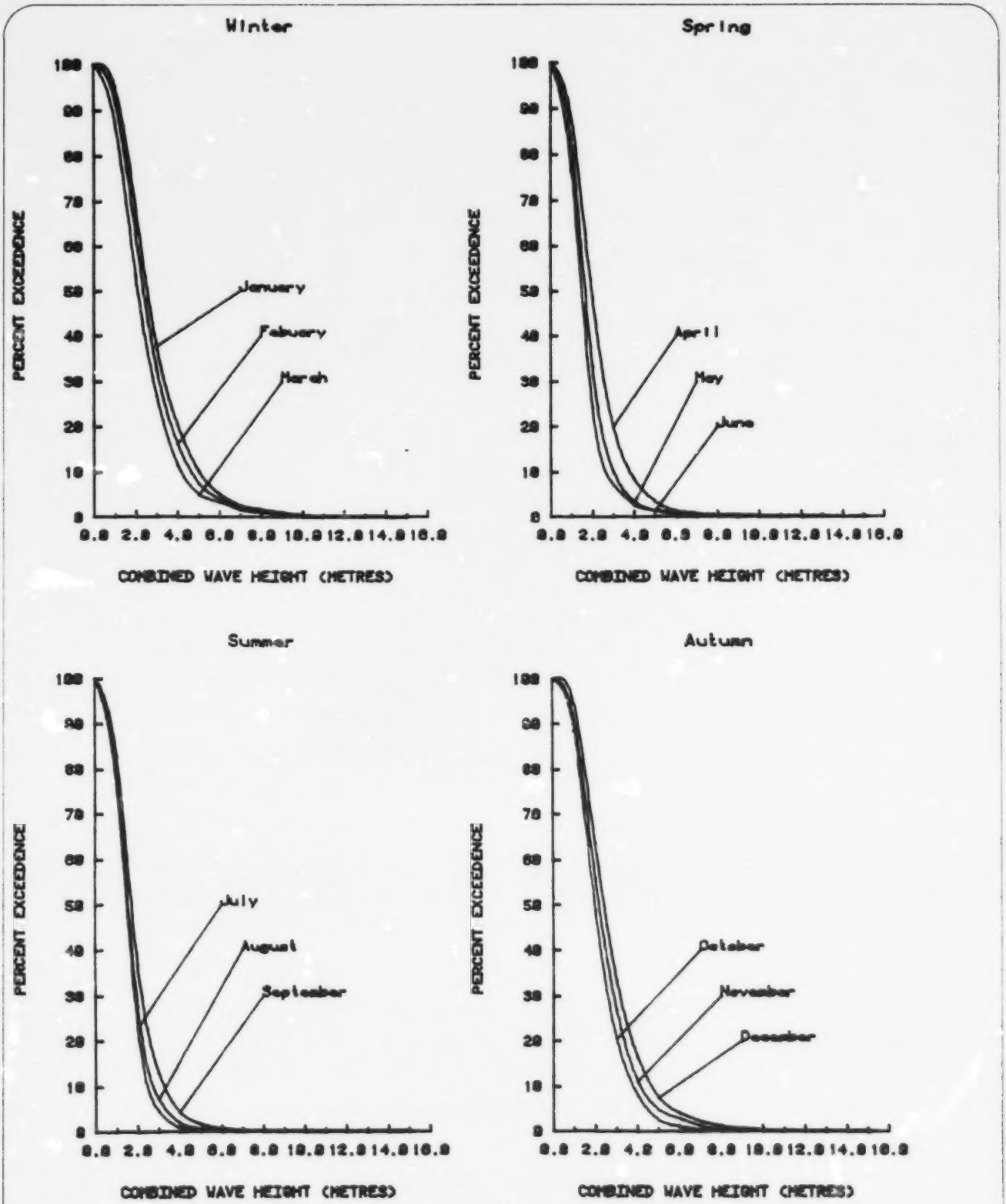
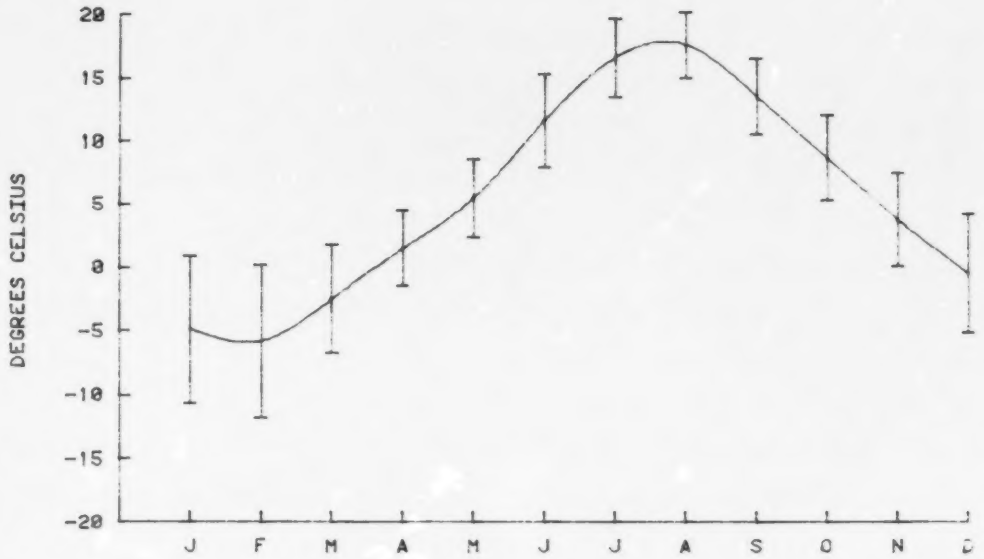


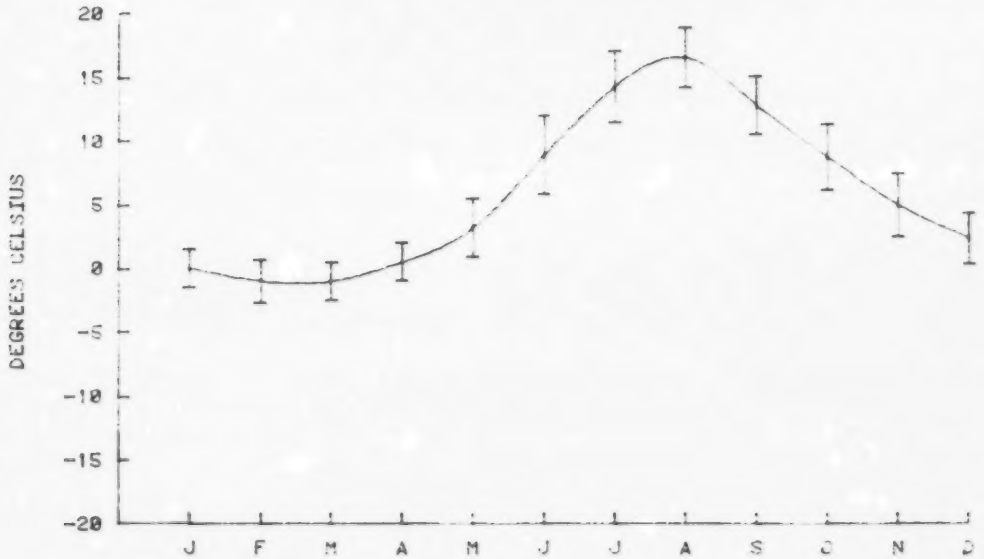
PERCENT EXCEEDENCE OF WIND SPEED
BANQUEREAU BANK MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
BANQUEREAU BANK MARINE FORECAST AREA

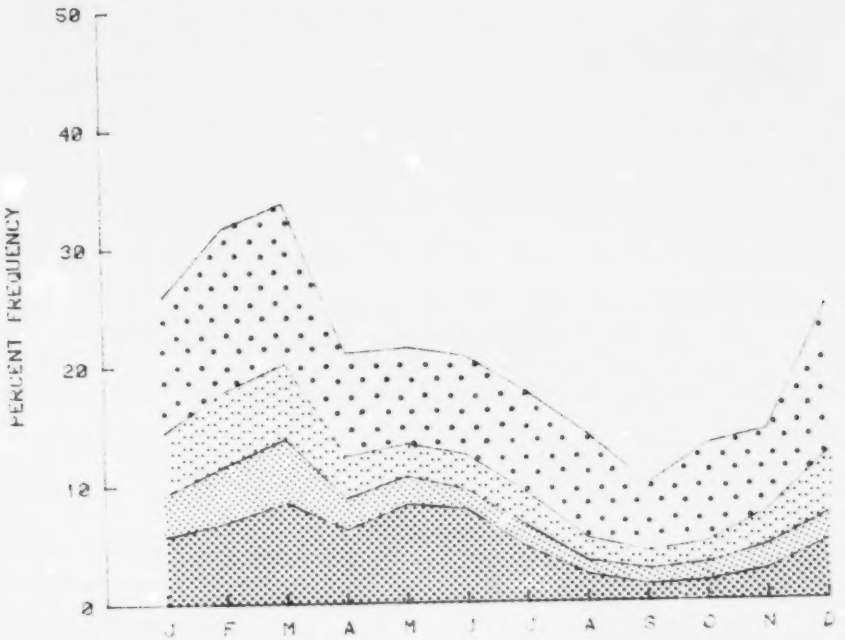


AIR TEMPERATURE



SEA SURFACE TEMPERATURE

GULF MAGDALEN MARINE FORECAST AREA



PERCENT FREQUENCY OF VISIBILITY
GULF MAGDALEN MARINE FORECAST AREA

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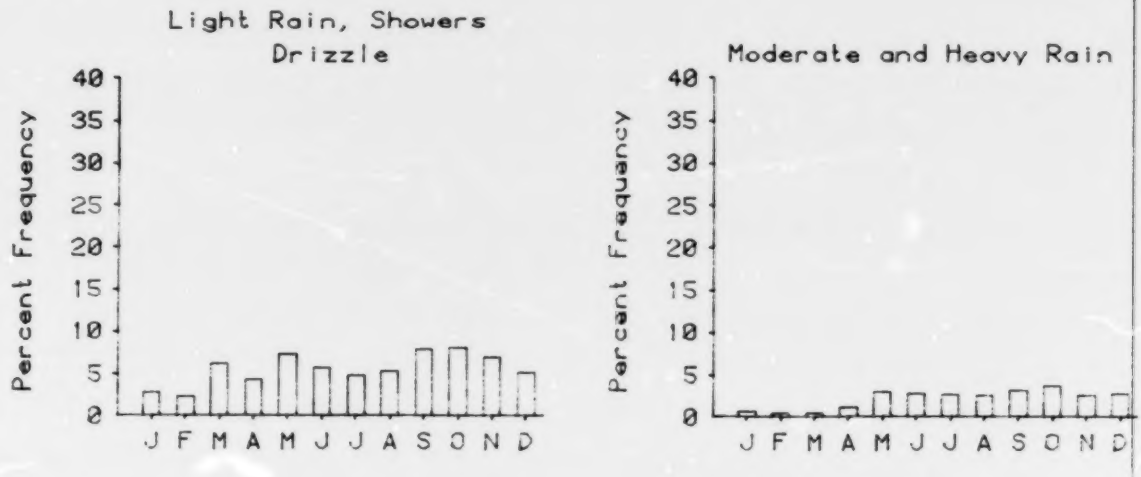
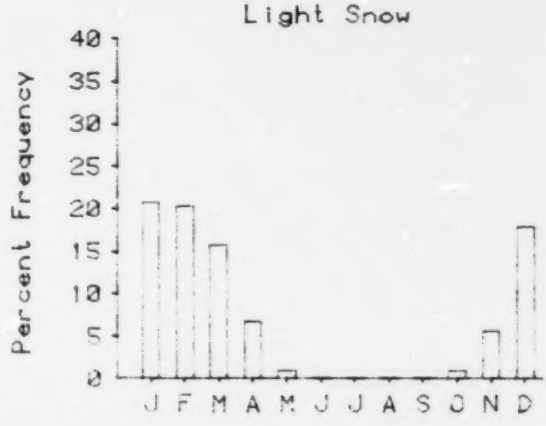
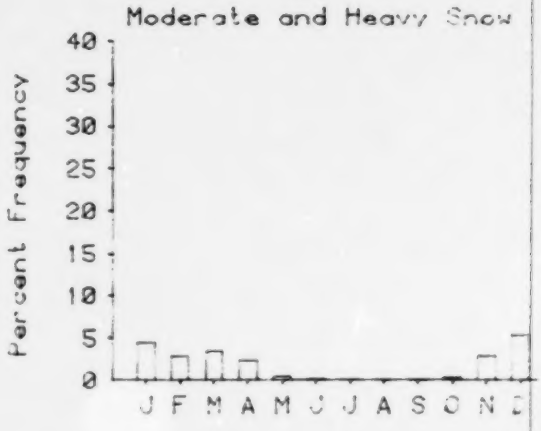
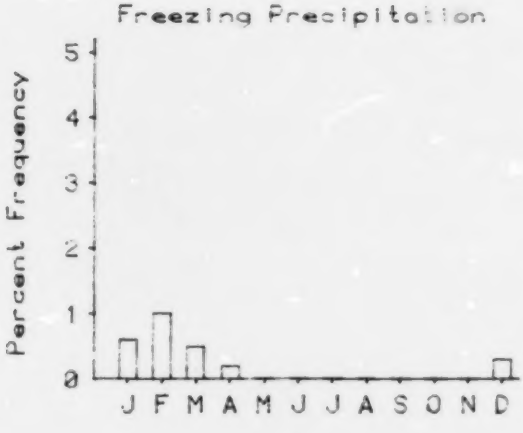
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES

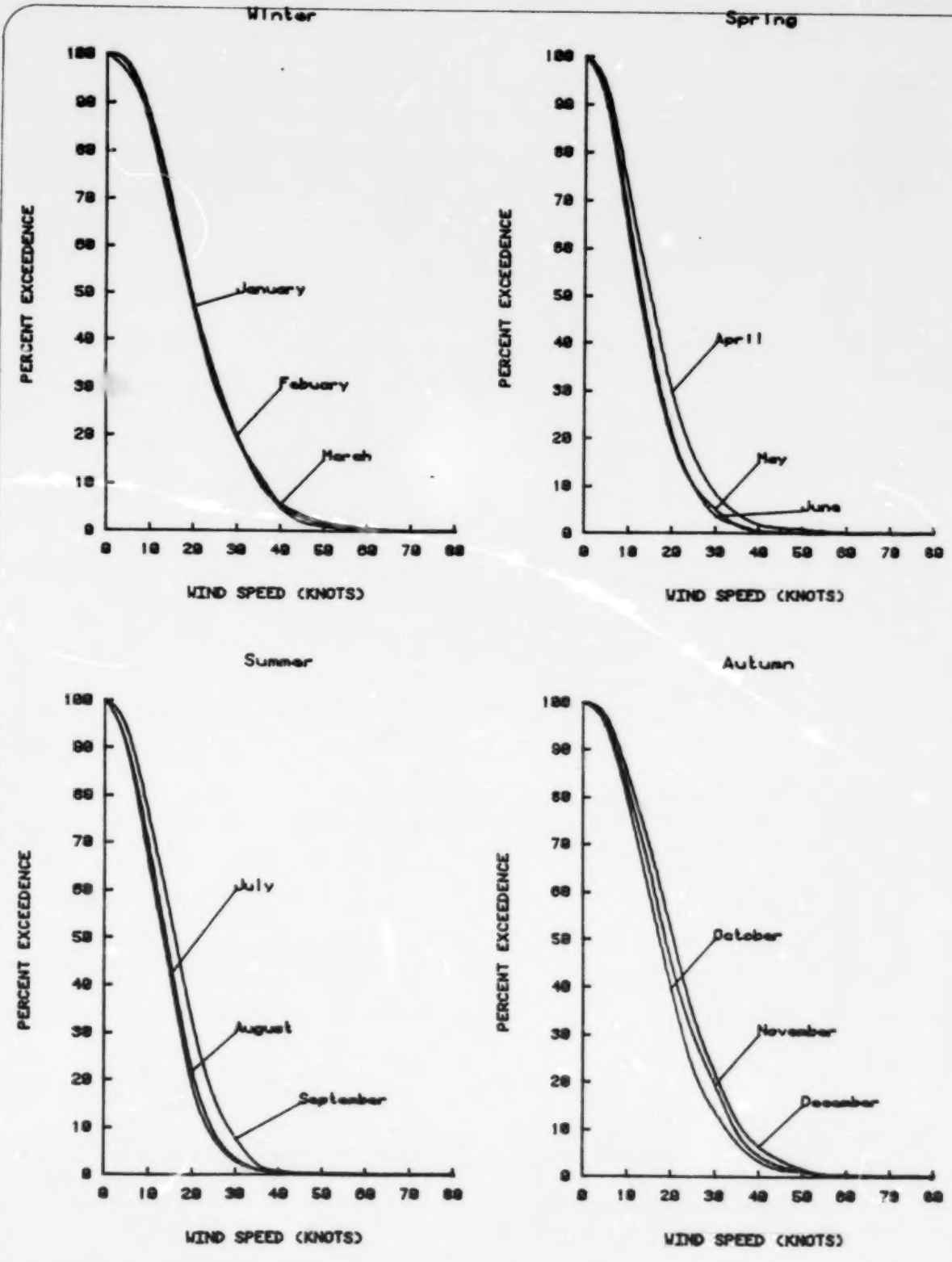




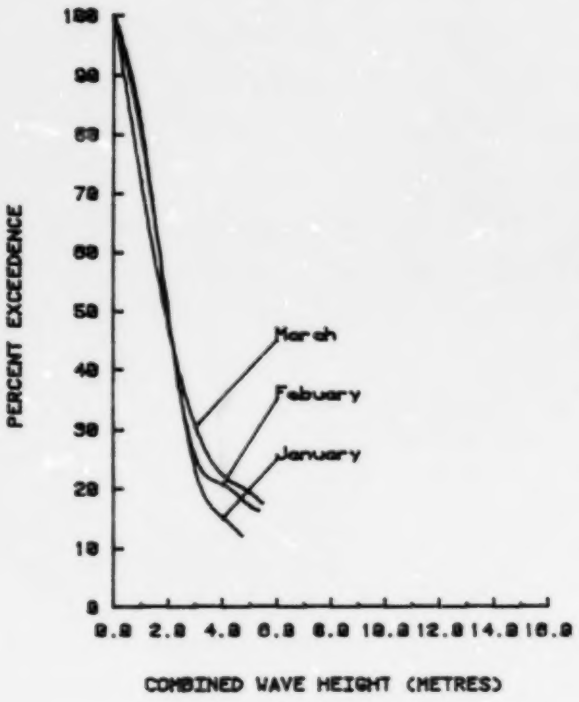


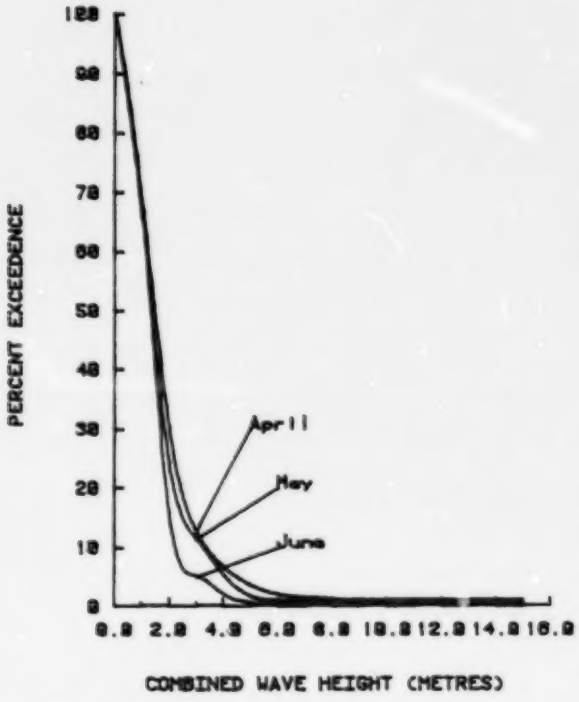


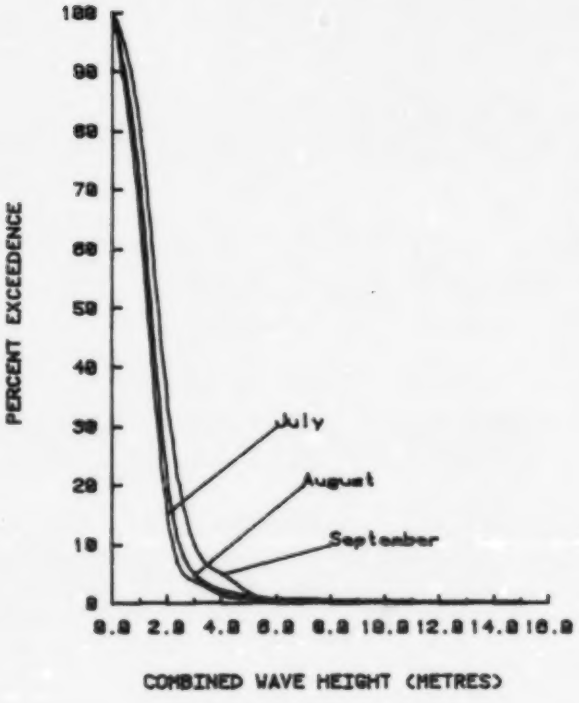
PERCENT FREQUENCY OF PRECIPITATION
GULF MAGDALEN MARINE FORECAST AREA

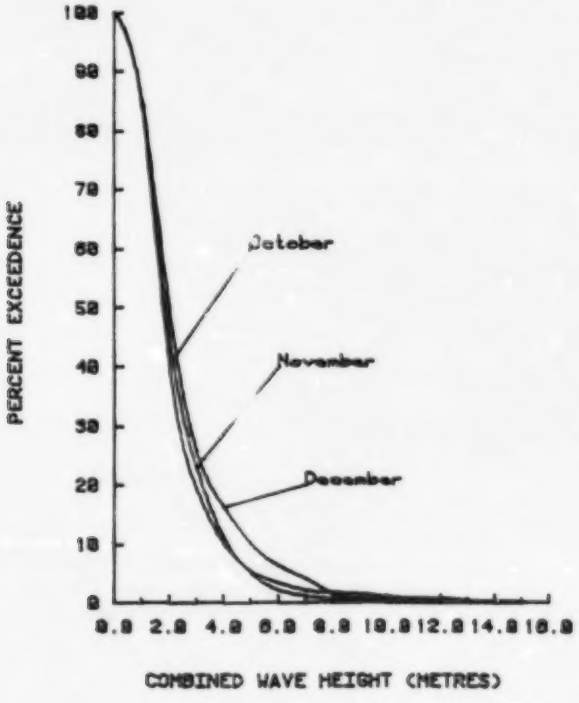


PERCENT EXCEEDENCE OF WIND SPEED
GULF MAGDALEN MARINE FORECAST AREA

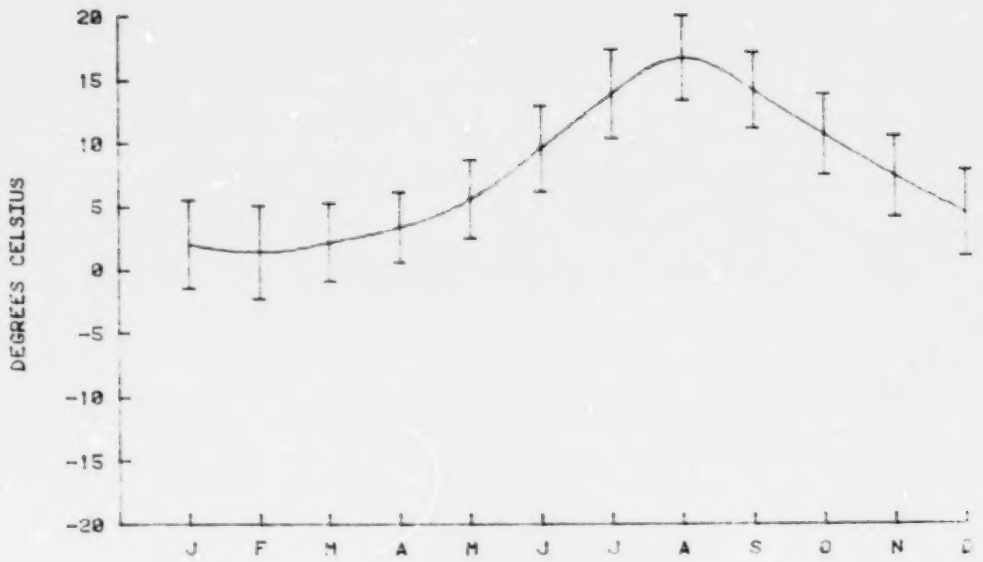




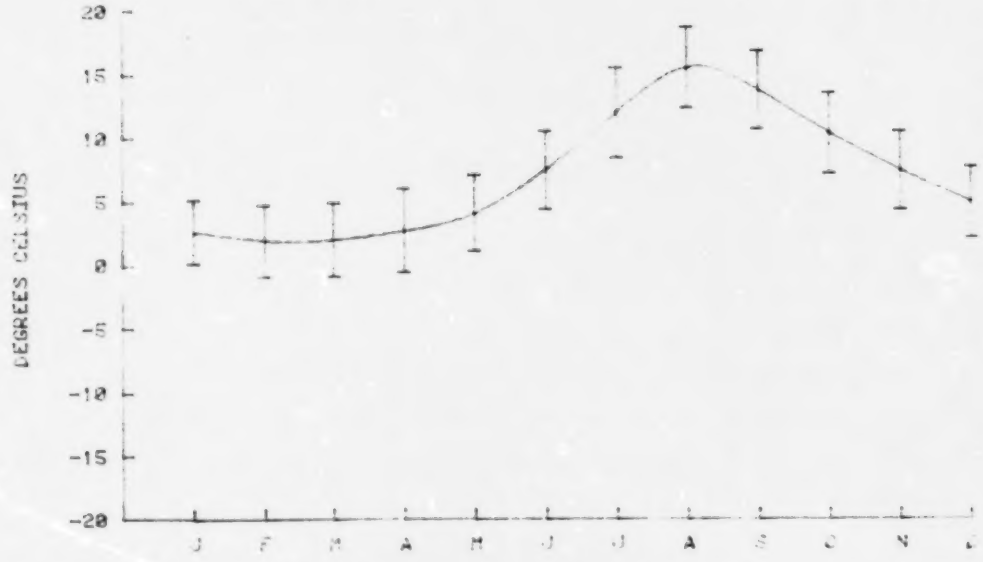




PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
GULF MAGDALEN MARINE FORECAST AREA

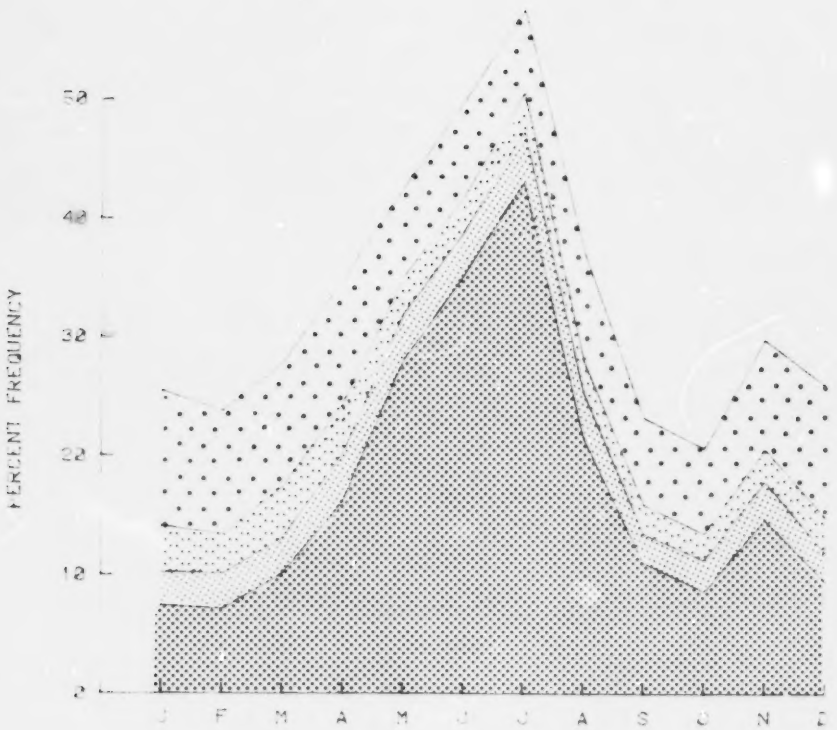


AIR TEMPERATURE



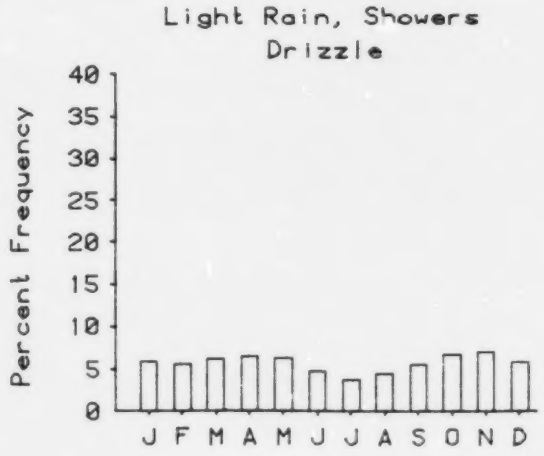
SEA SURFACE TEMPERATURE

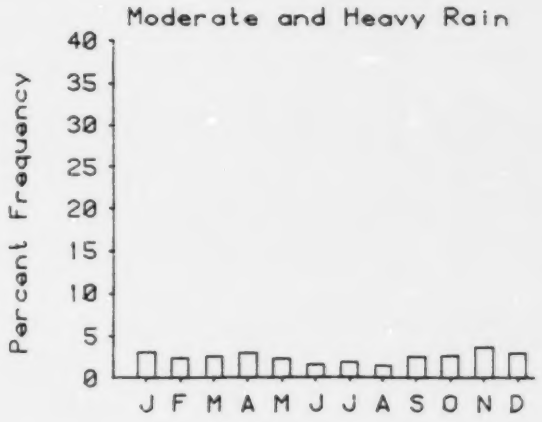
SOUTHEASTERN GRAND BANK MARINE FORECAST AREA

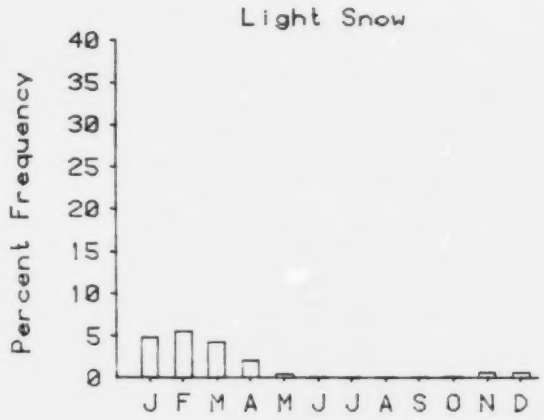


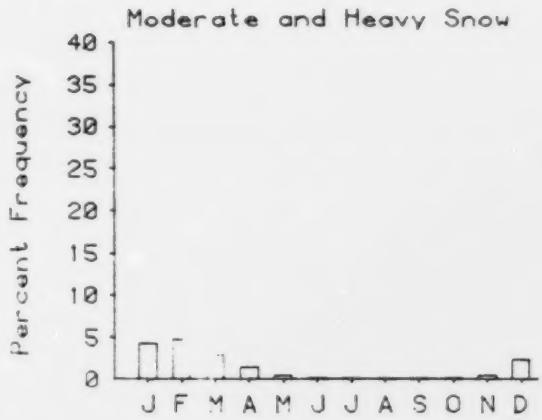
PERCENT FREQUENCY OF VISIBILITY
SOUTHEASTERN GRAND BANKS MARINE FORECAST AREA

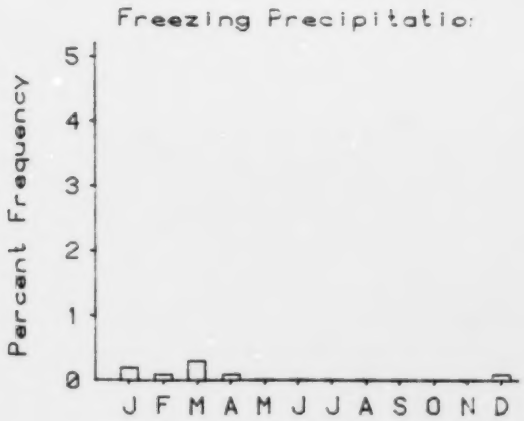
< **5.4** NAUTICAL MILES
< **2.2** NAUTICAL MILES
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES



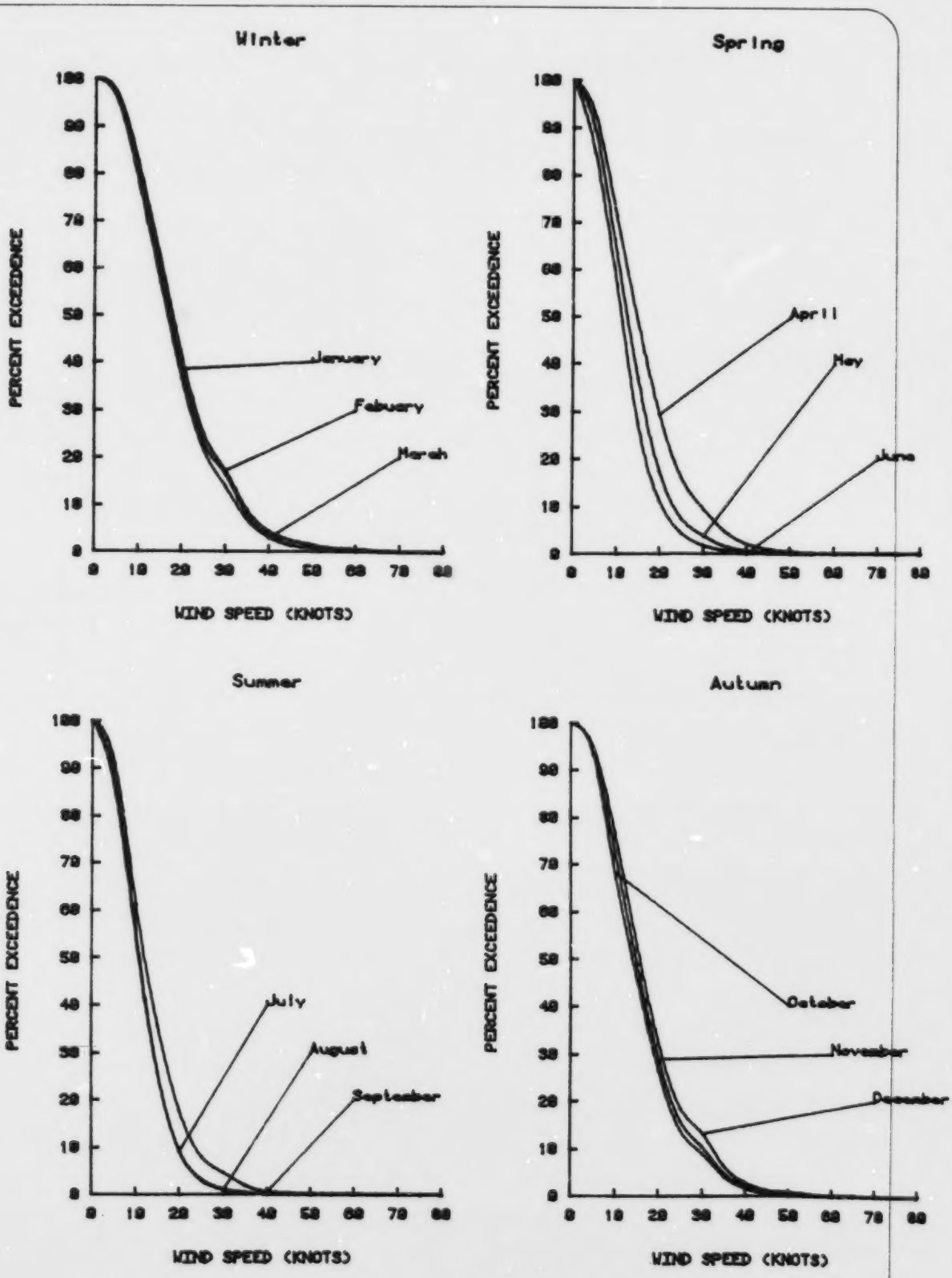




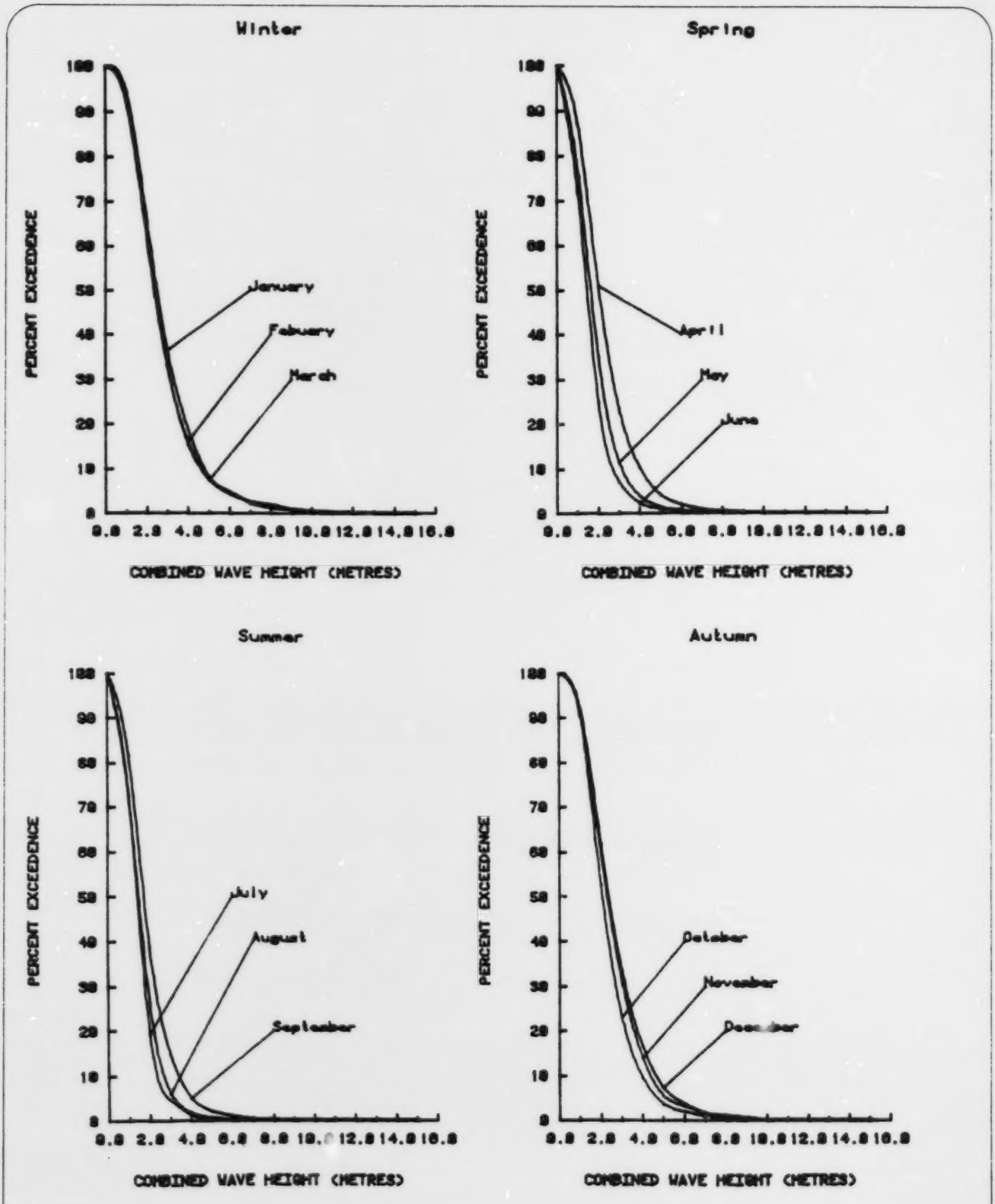




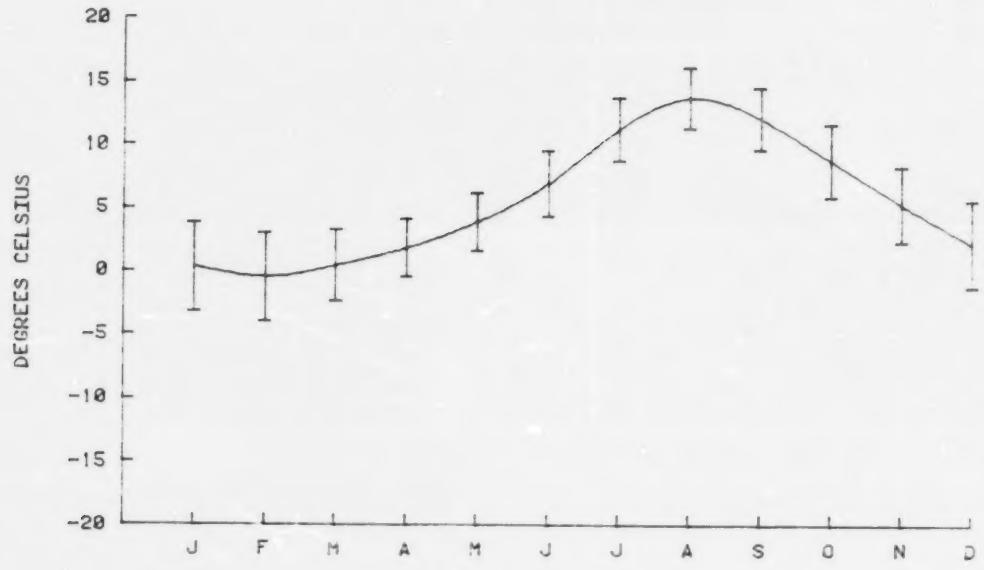
PERCENT FREQUENCY OF PRECIPITATION
SOUTHEASTERN GRAND BANKS MARINE FORECAST AREA



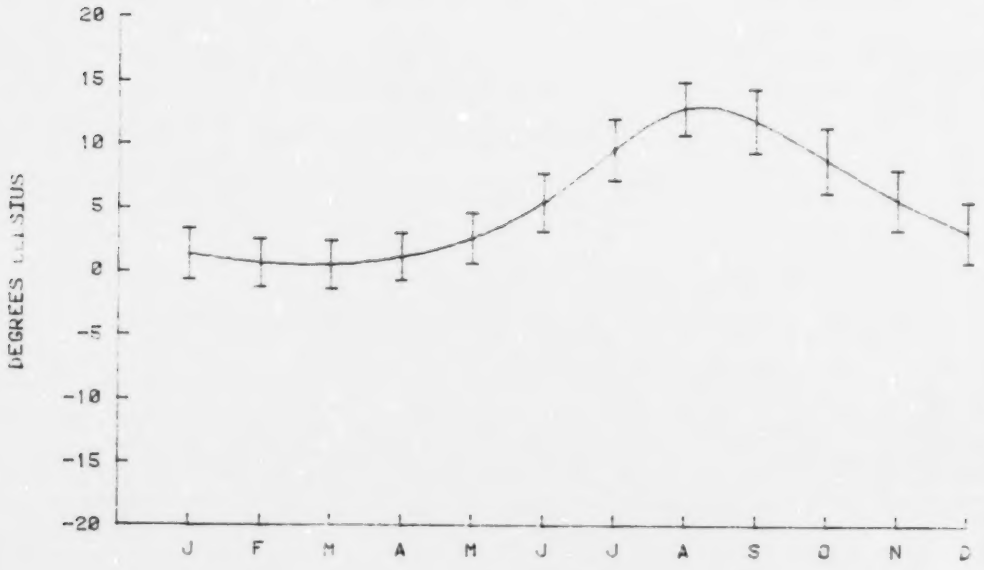
PERCENT EXCEEDENCE OF WIND SPEED
SOUTHEASTERN GRAND BANKS MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
SOUTHEASTERN GRAND BANKS MARINE FORECAST AREA

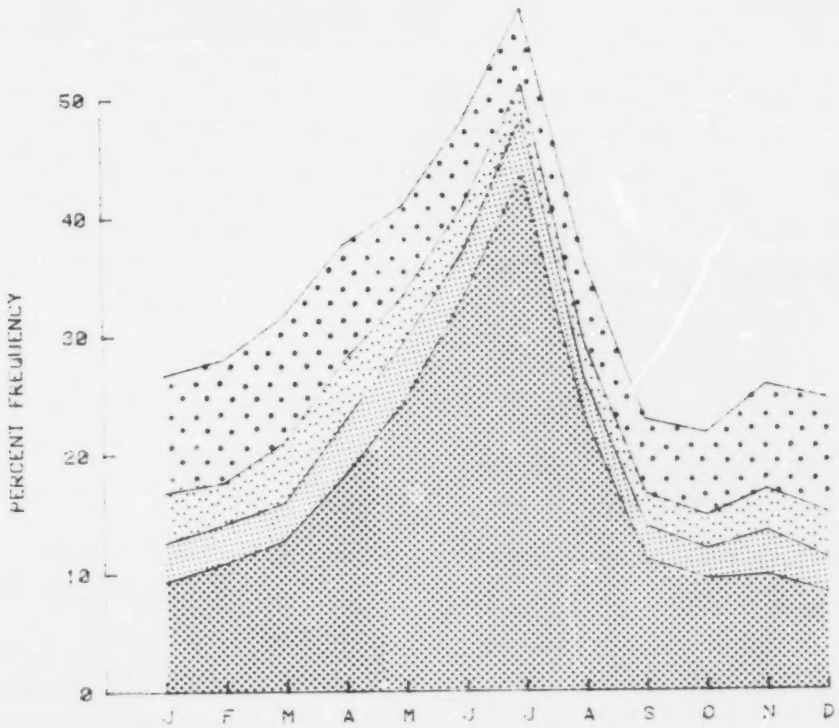


AIR TEMPERATURE



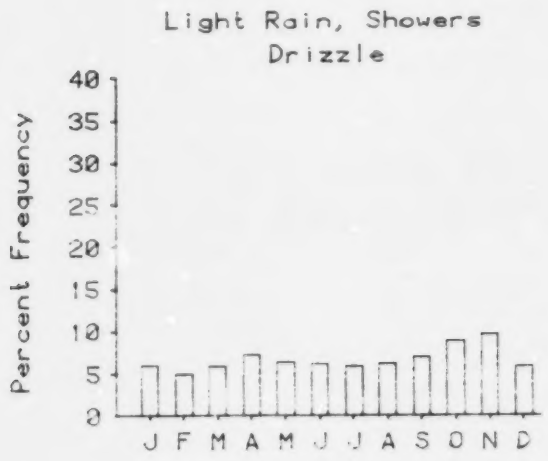
SEA SURFACE TEMPERATURE

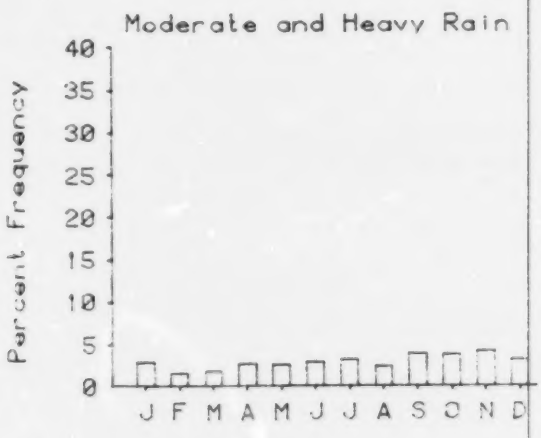
NORTHERN GRAND BANKS MARINE FORECAST AREA

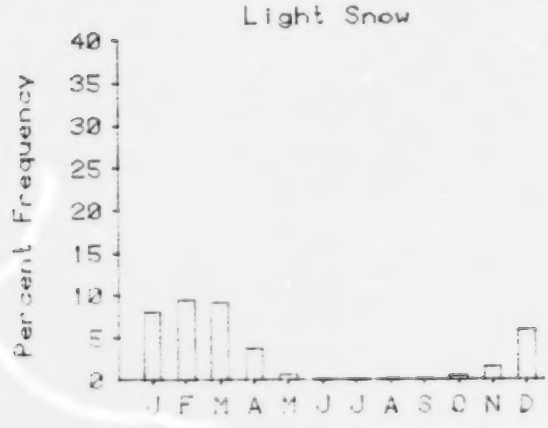


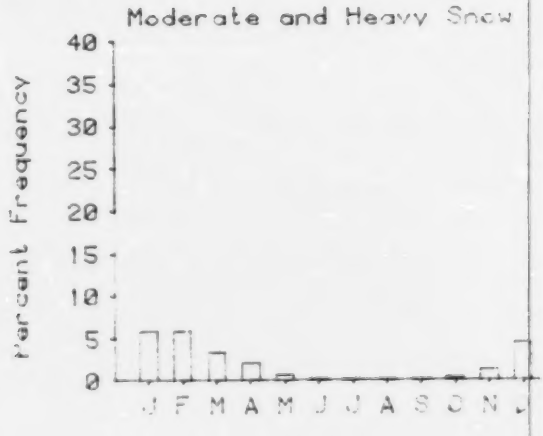
PERCENT FREQUENCY OF VISIBILITY
NORTHERN GRAND BANKS MARINE FORECAST AREA

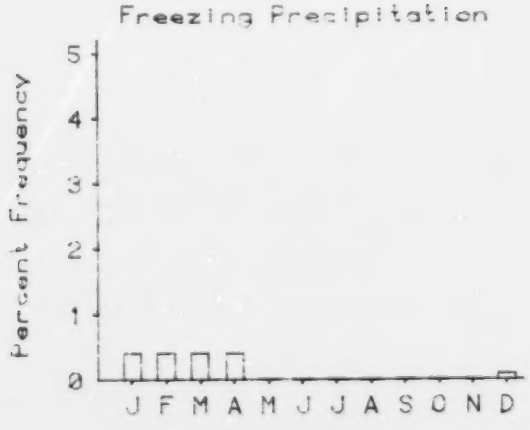
< **5.4** NAUTICAL MILES
< **2.2** NAUTICAL MILES
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES



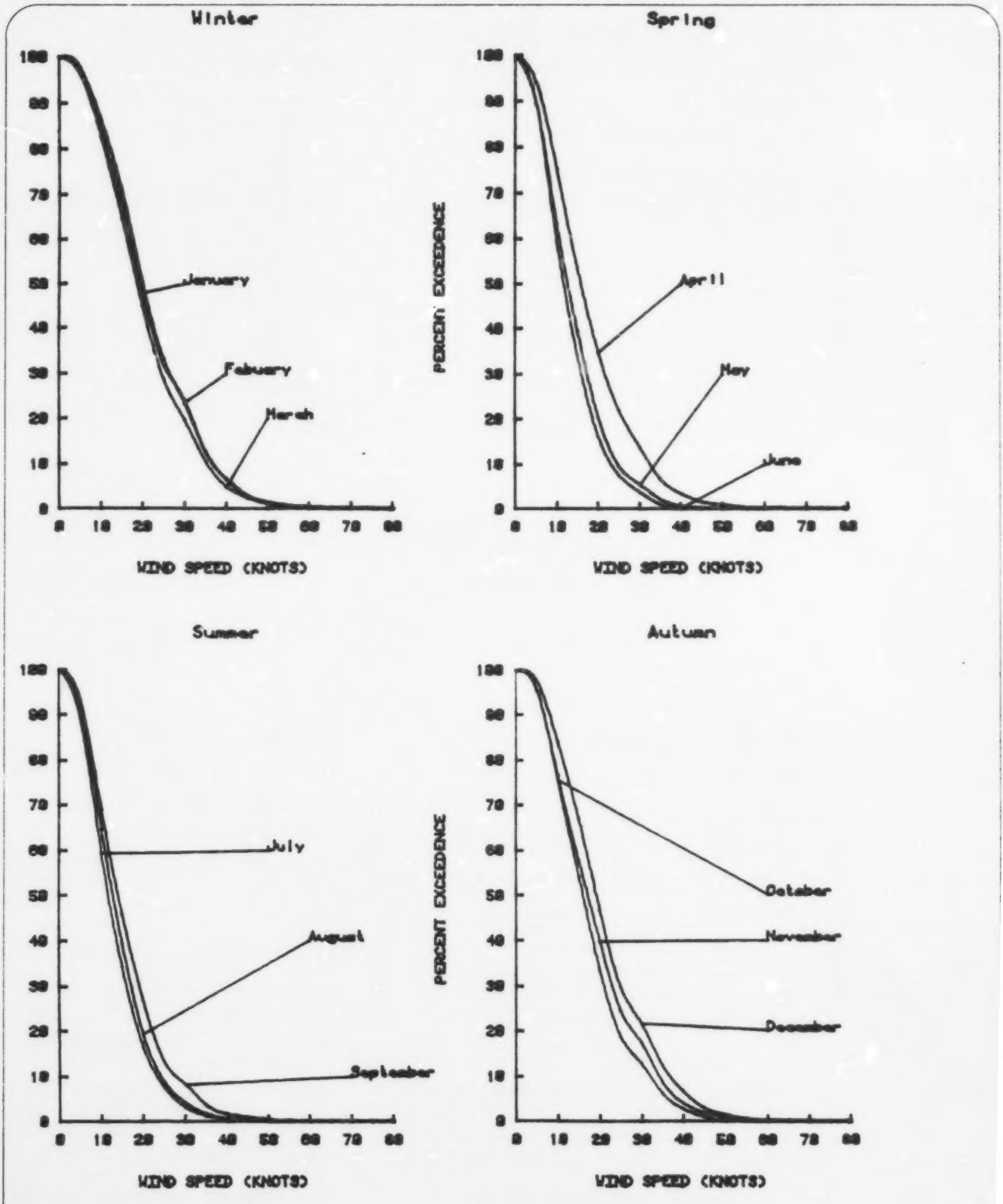




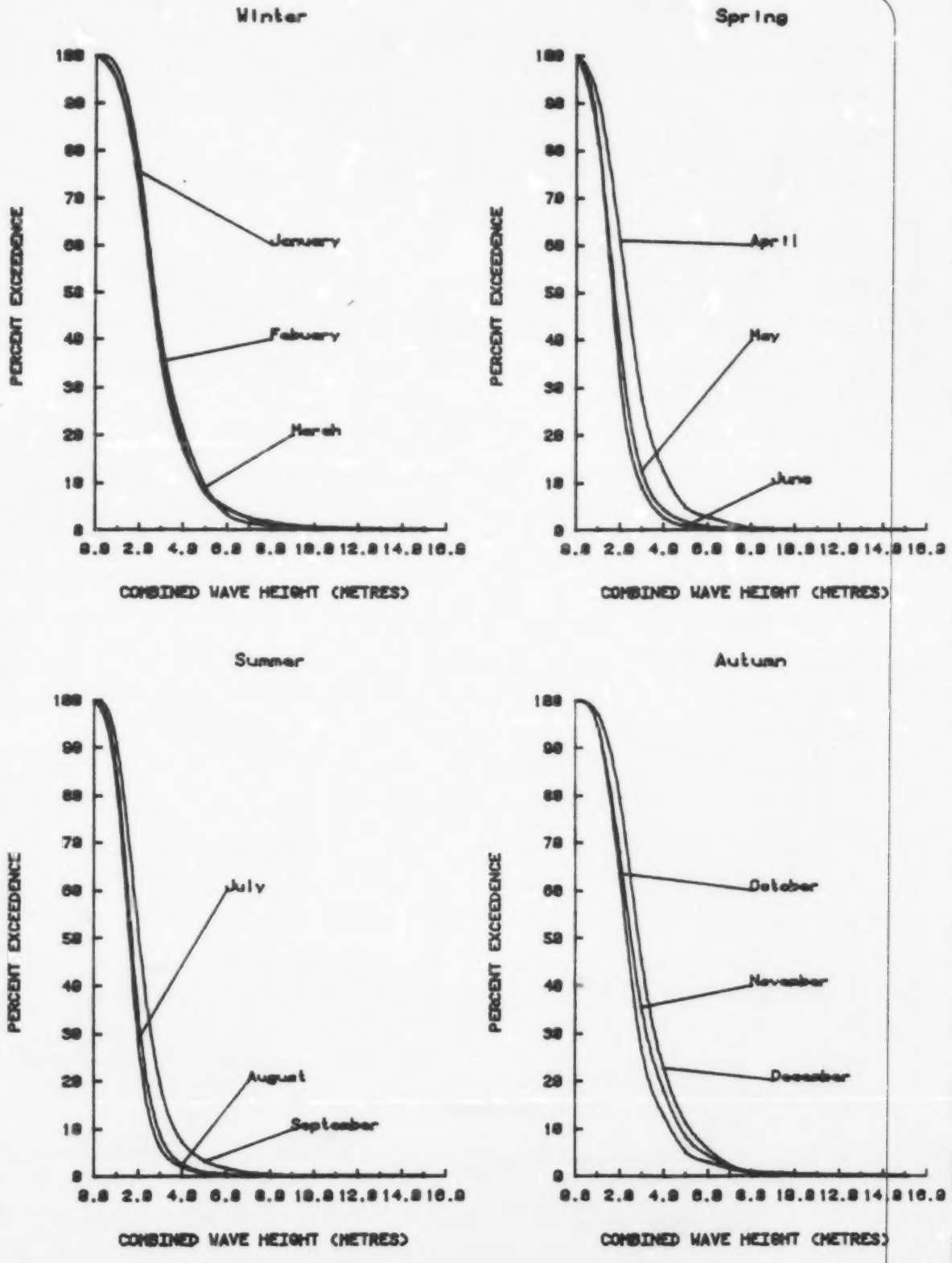




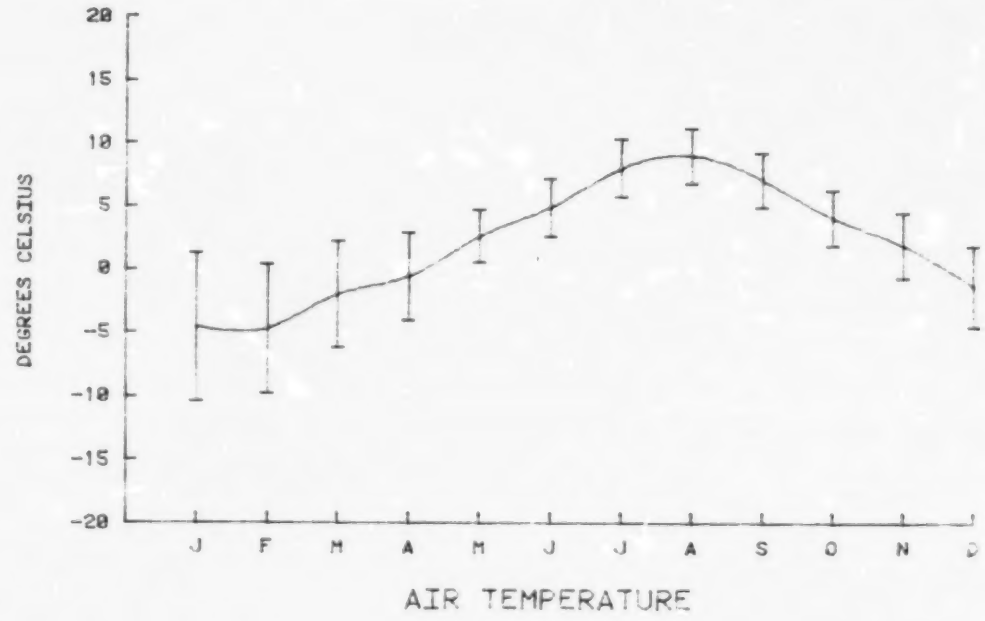
PERCENT FREQUENCY OF PRECIPITATION
NORTHERN GRAND BANKS MARINE FORECAST AREA



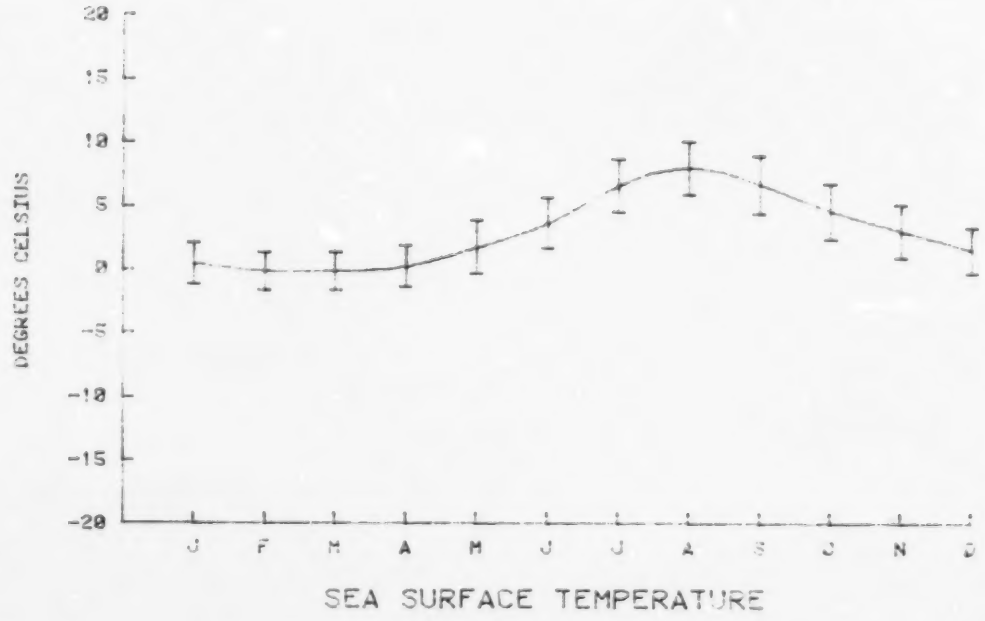
PERCENT EXCEEDENCE OF WIND SPEED
NORTHERN GRAND BANKS MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
NORTHERN GRAND BANKS MARINE FORECAST AREA

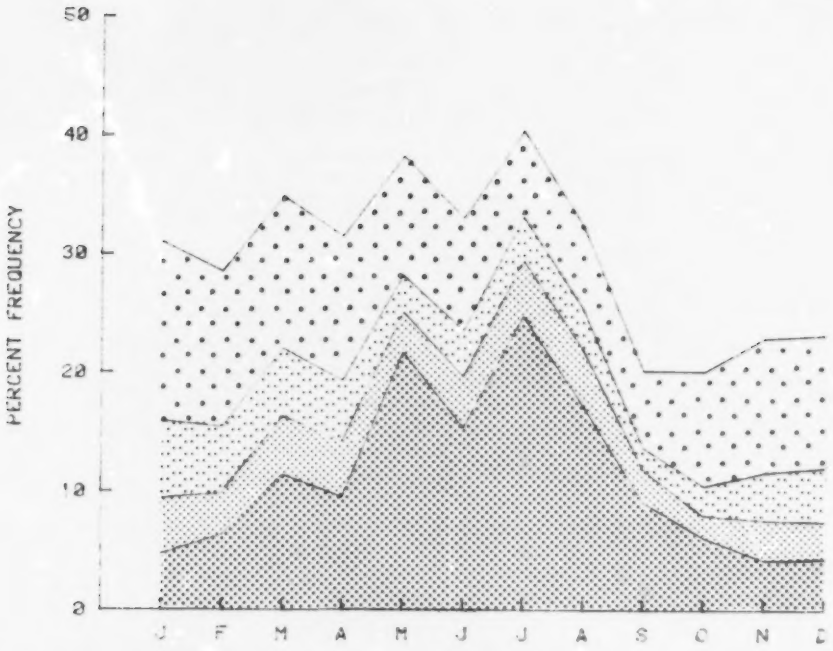


AIR TEMPERATURE



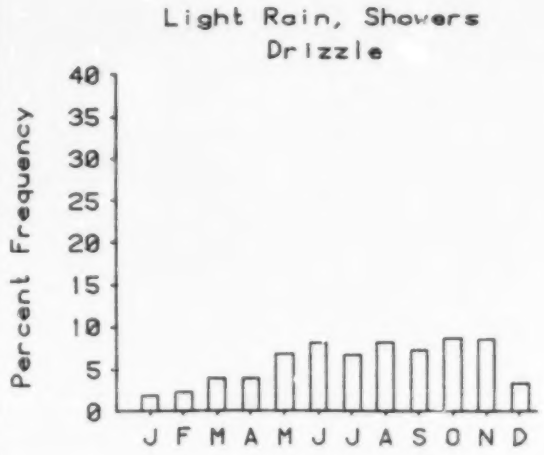
SEA SURFACE TEMPERATURE

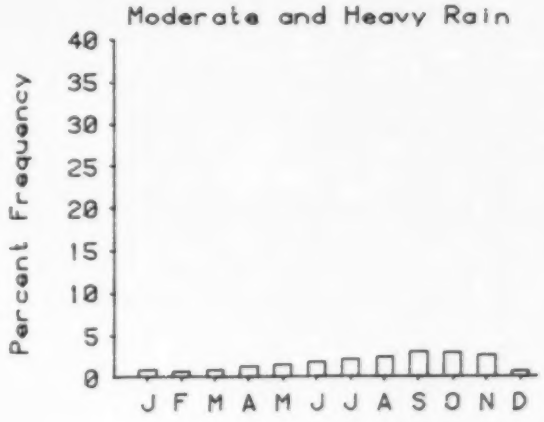
BELLE ISLE BANK MARINE FORECAST AREA

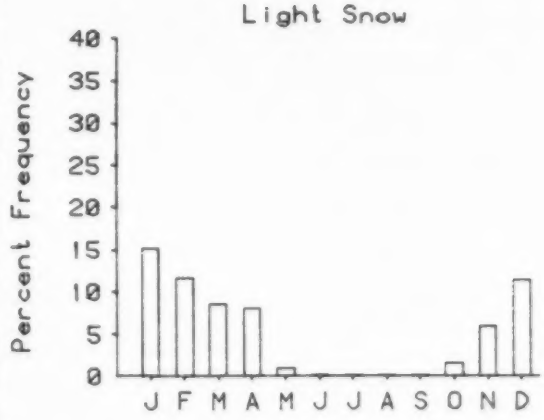


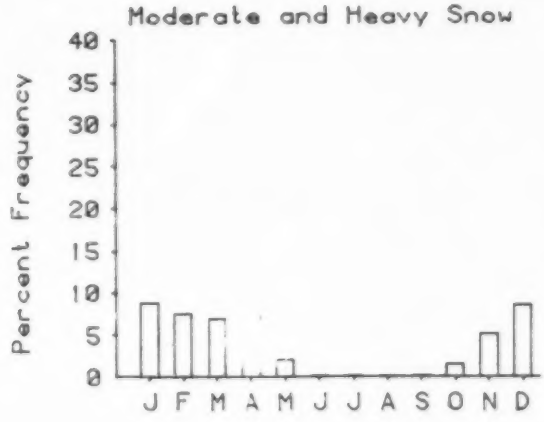
PERCENT FREQUENCY OF VISIBILITY
BELLE ISLE BANK MARINE FORECAST AREA

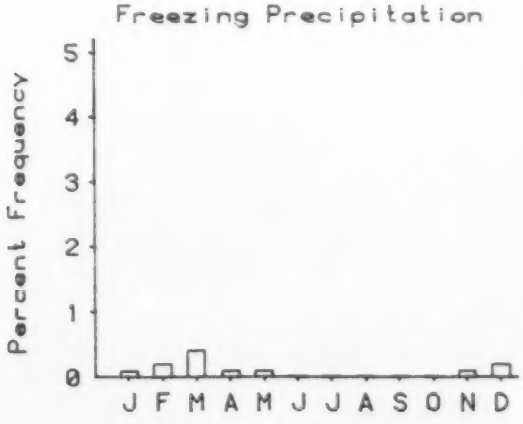
< **5.4** NAUTICAL MILES
< **2.2** NAUTICAL MILES
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES



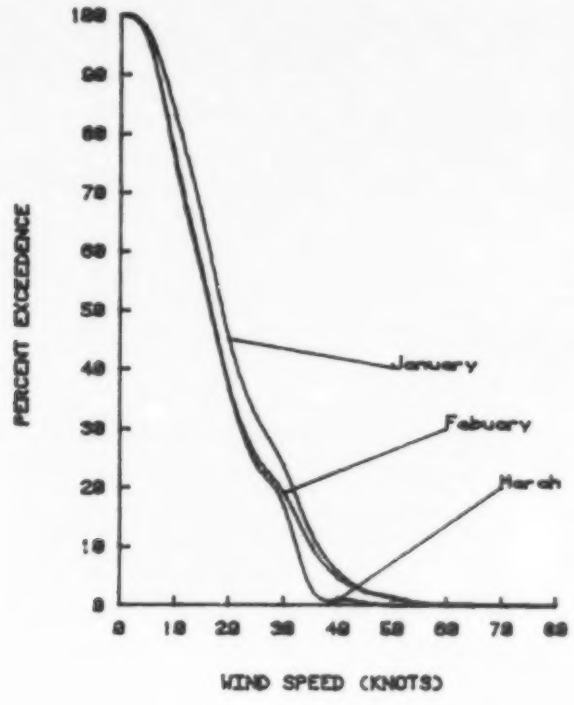


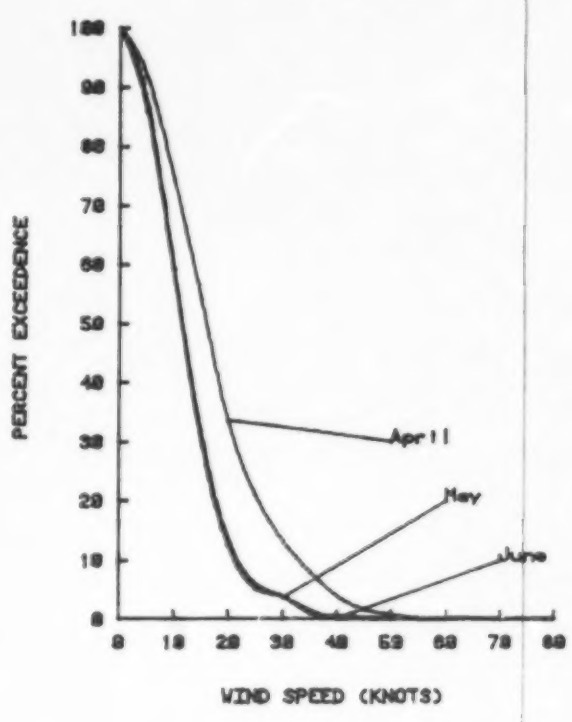


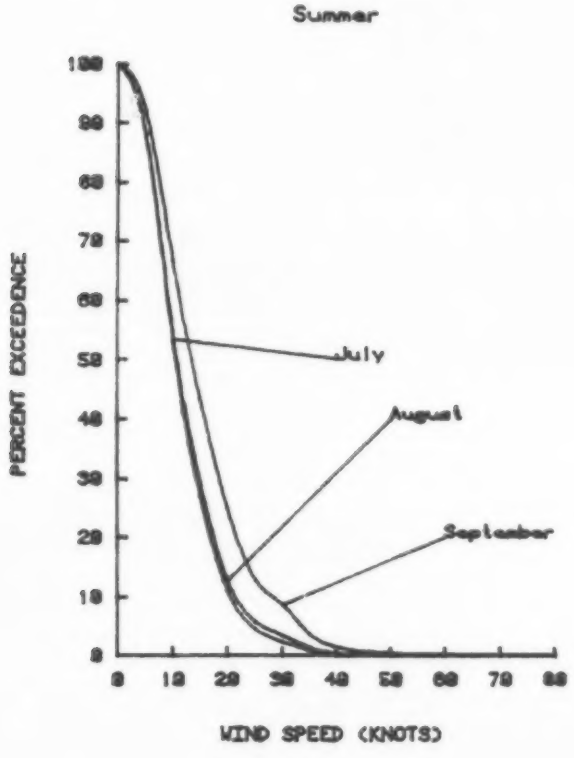


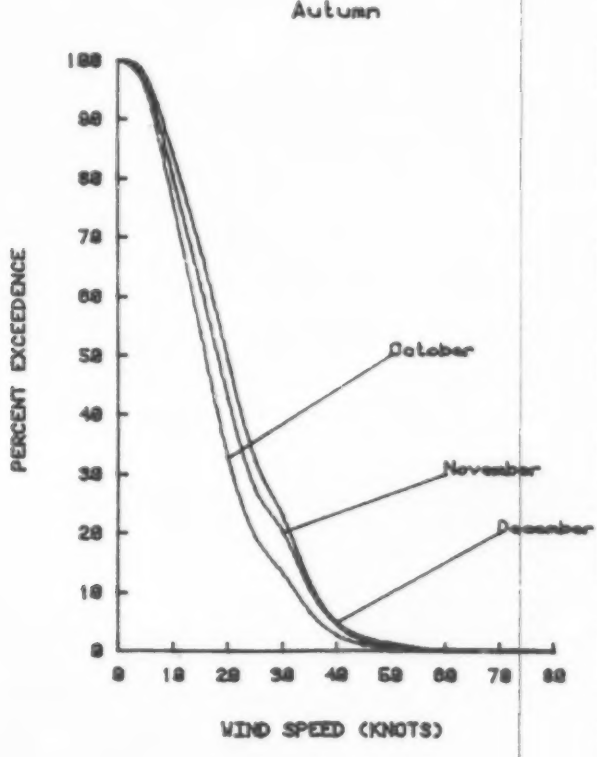


PERCENT FREQUENCY OF PRECIPITATION
BELLE ISLE BANK MARINE FORECAST AREA

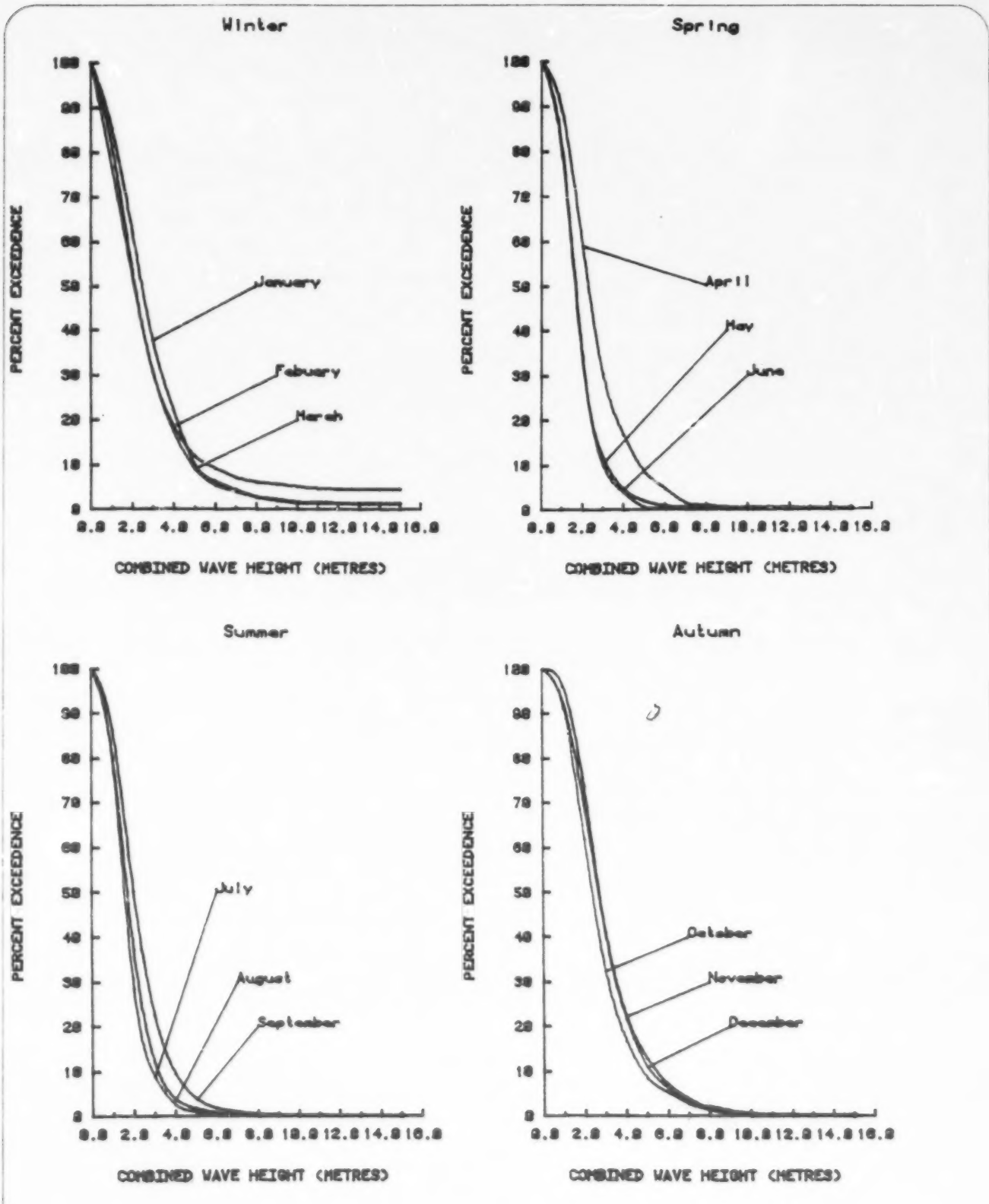




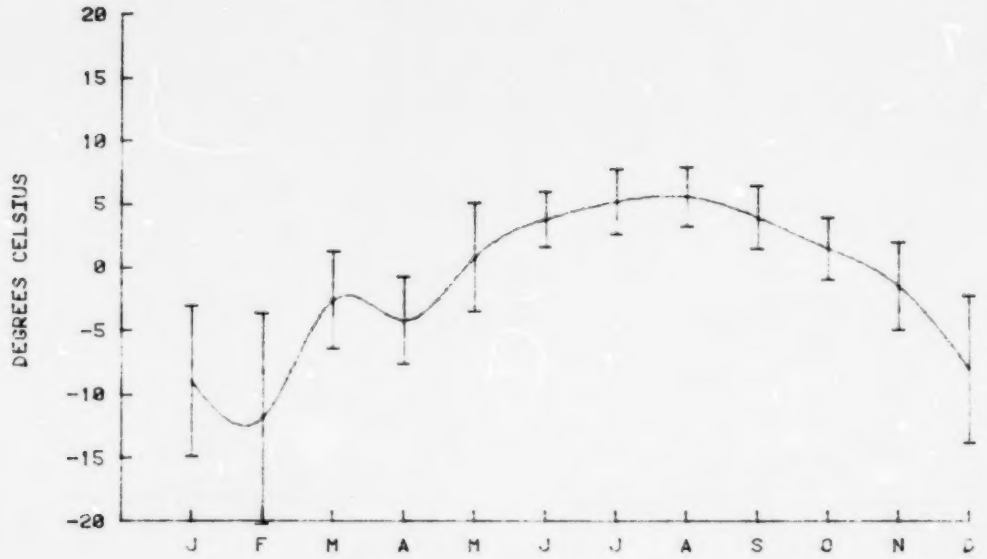




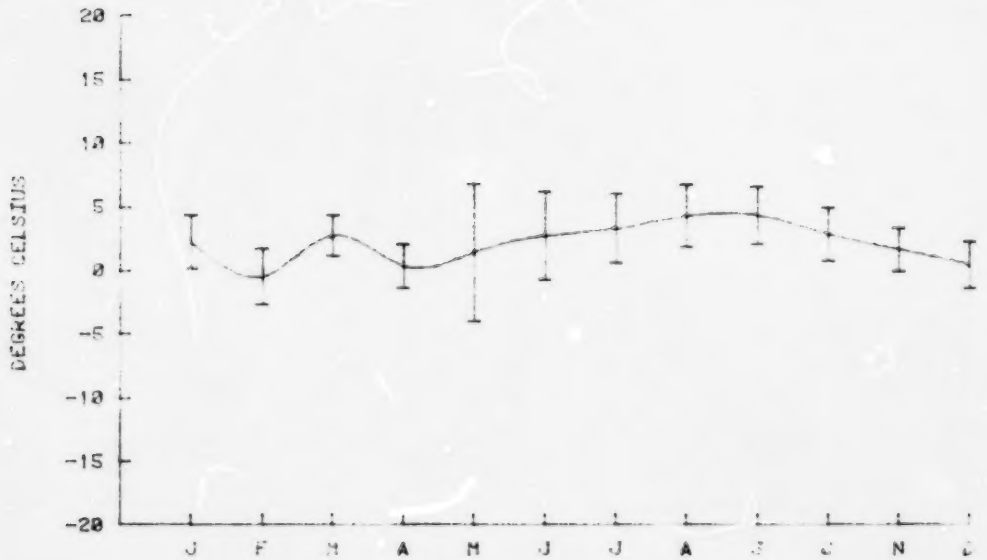
PERCENT EXCEEDENCE OF WIND SPEED
BELLE ISLE BANK MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
BELLE ISLE BANK MARINE FORECAST AREA

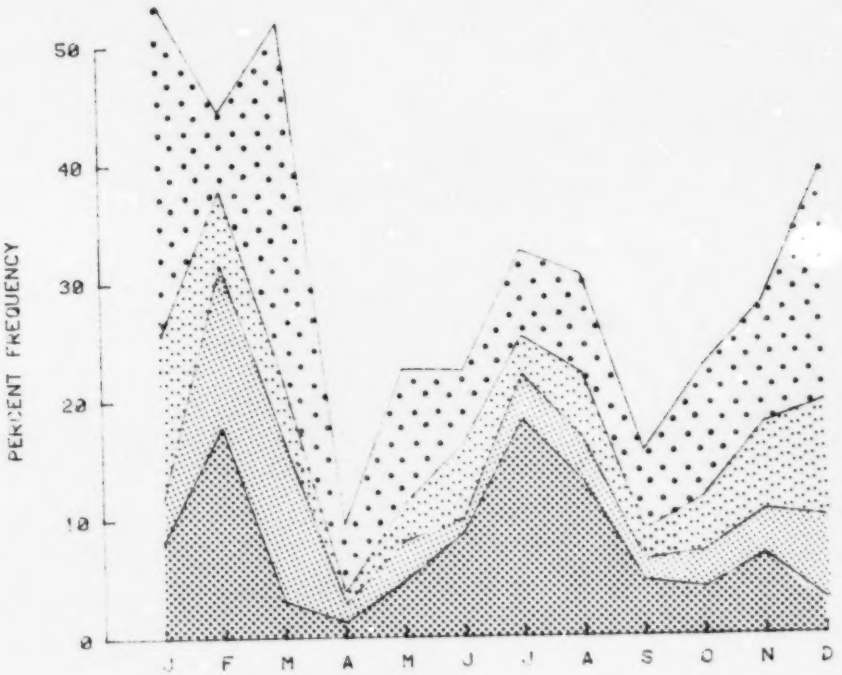


AIR TEMPERATURE



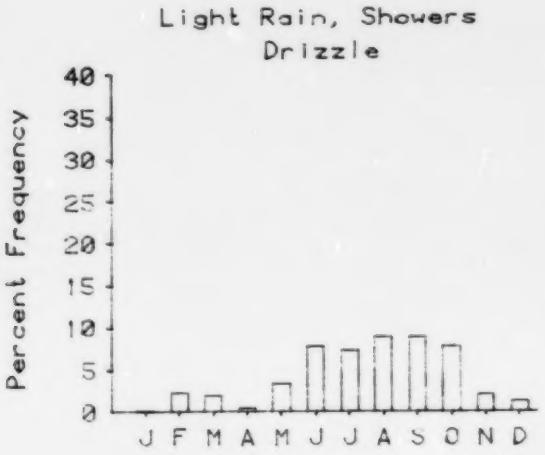
SEA SURFACE TEMPERATURE

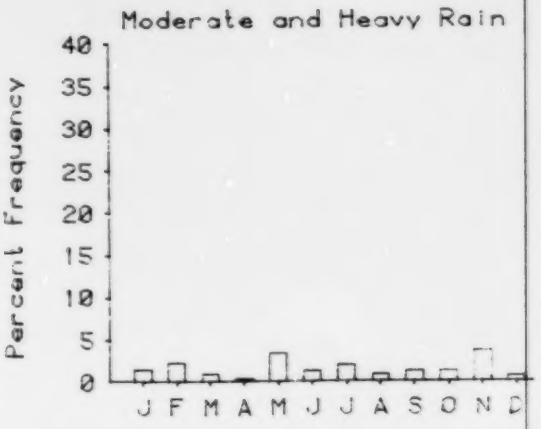
NORTHWEST LABRADOR SEA MARINE FORECAST AREA

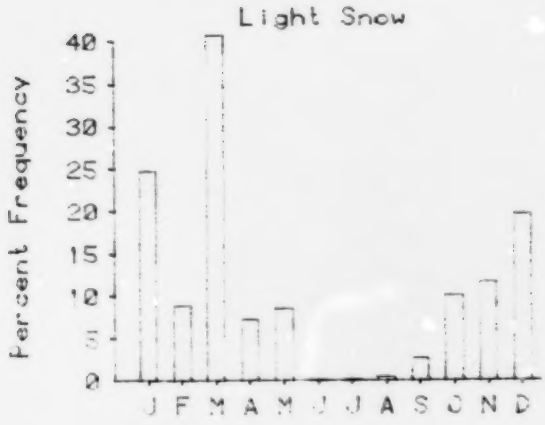


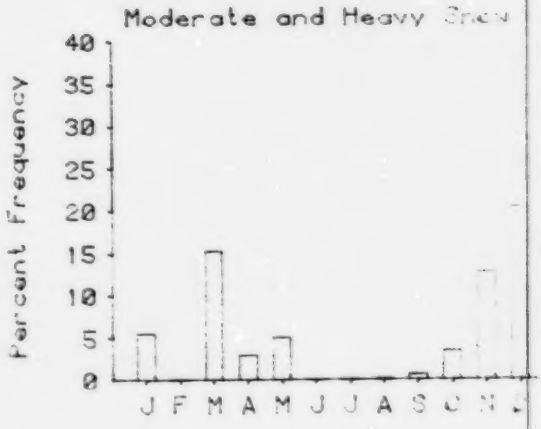
PERCENT FREQUENCY OF VISIBILITY
NORTHWEST LABRADOR SEA MARINE FORECAST AREA

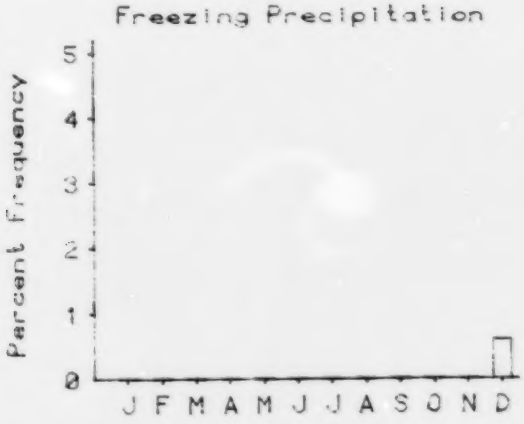
< **5.4** NAUTICAL MILES
< **2.2** NAUTICAL MILES
< **1.1** NAUTICAL MILES
< **0.5** NAUTICAL MILES



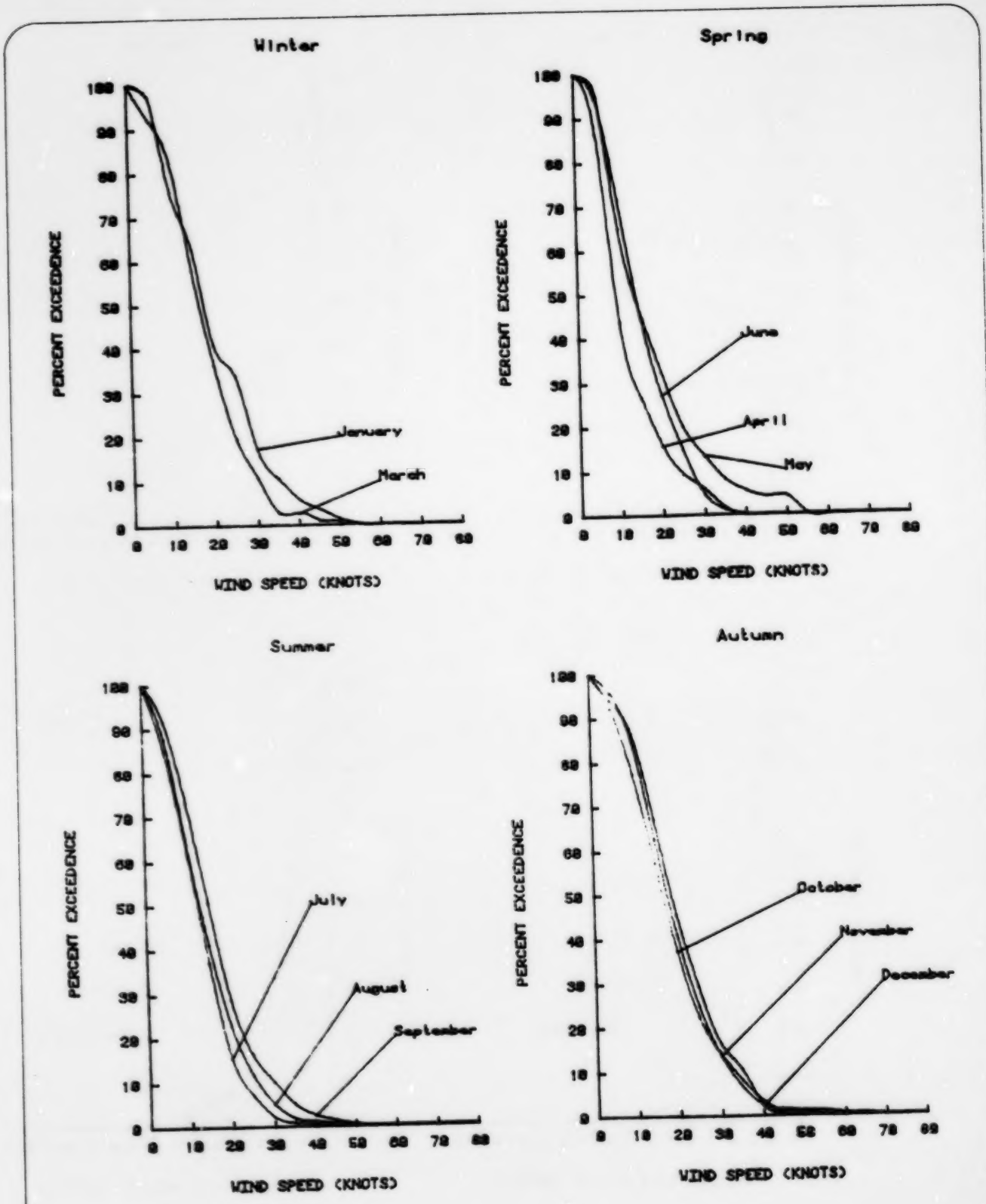




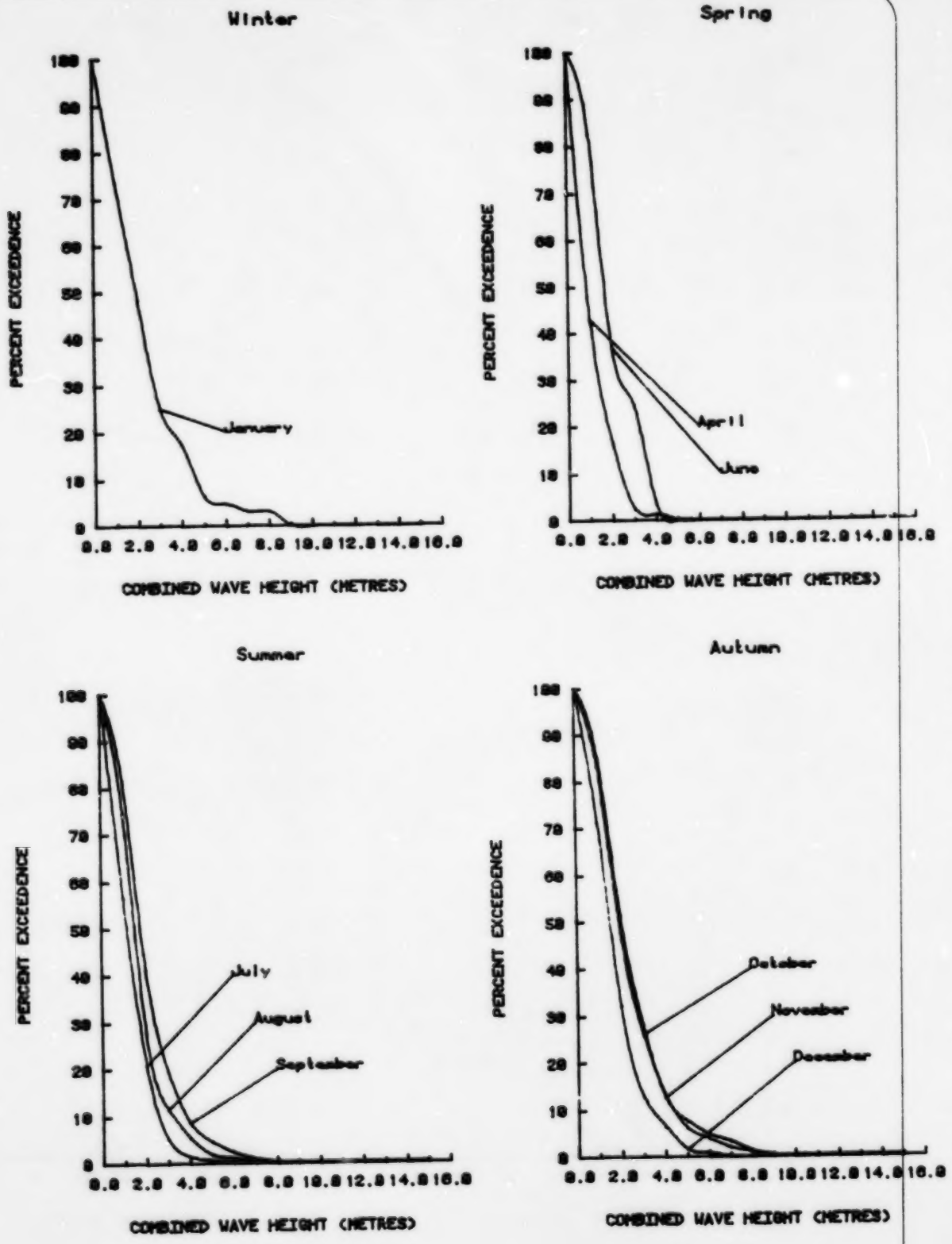




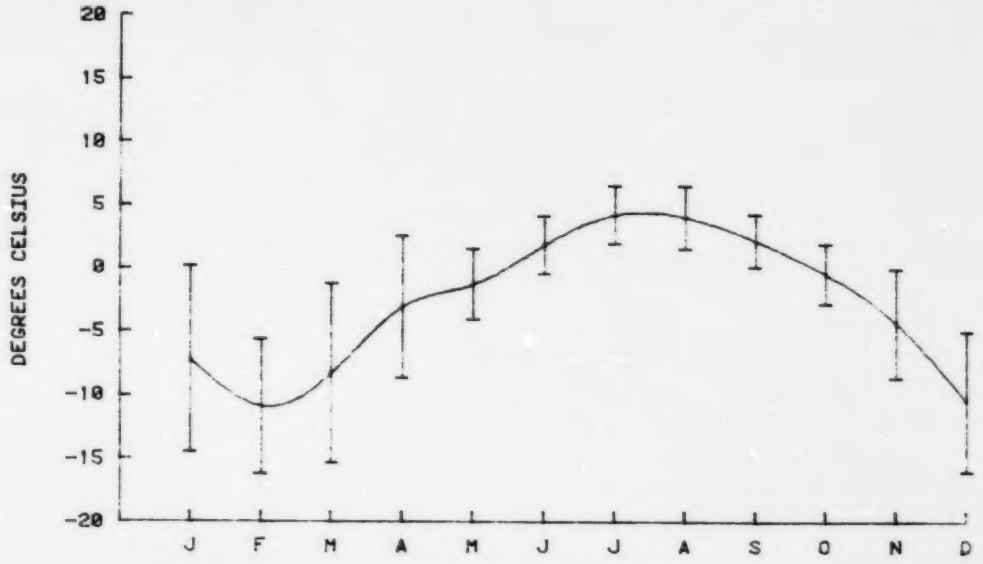
PERCENT FREQUENCY OF PRECIPITATION
NORTHWEST LABRADOR SEA MARINE FORECAST AREA



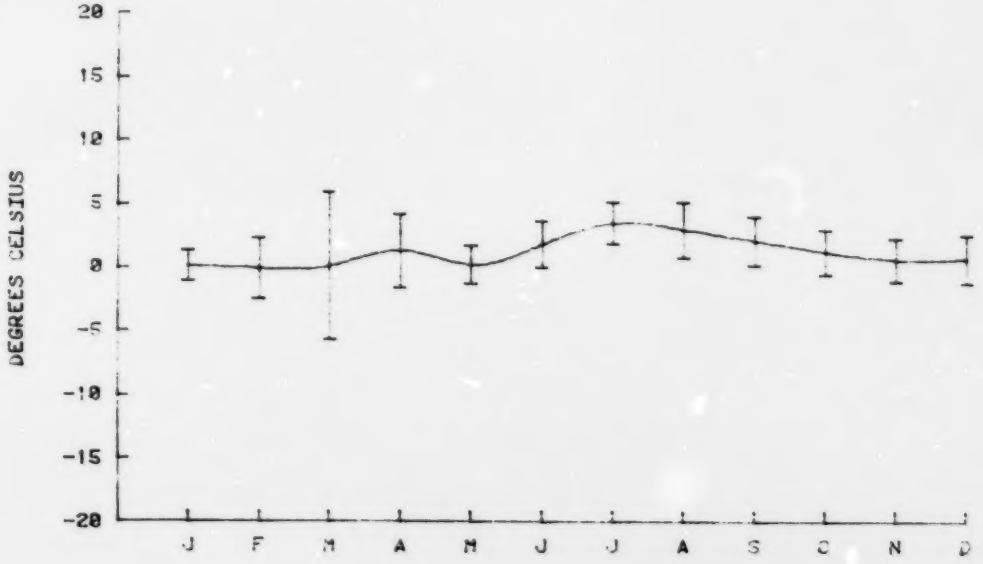
PERCENT EXCEEDENCE OF WIND SPEED
NORTHWEST LABRADOR SEA MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
NORTHWEST LABRADOR SEA MARINE FORECAST AREA

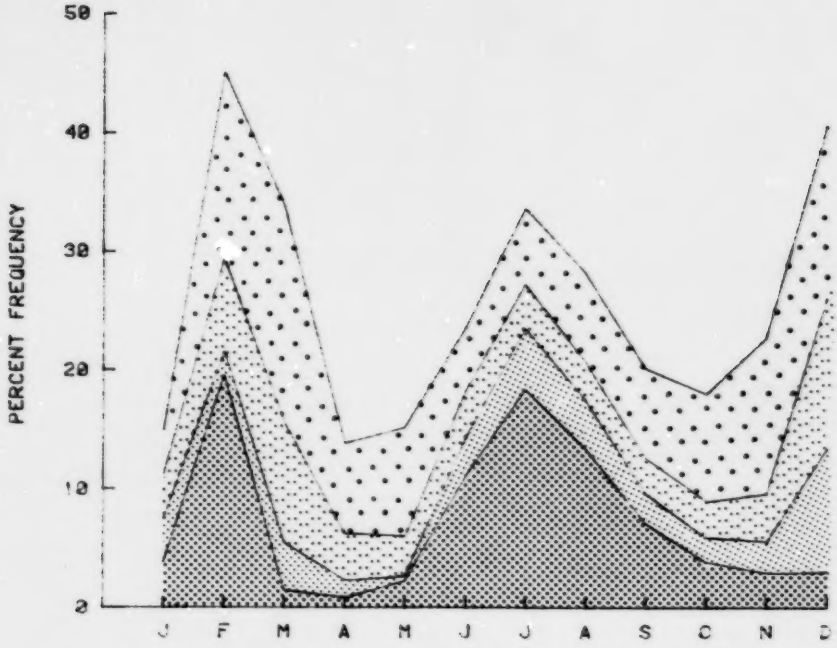


AIR TEMPERATURE



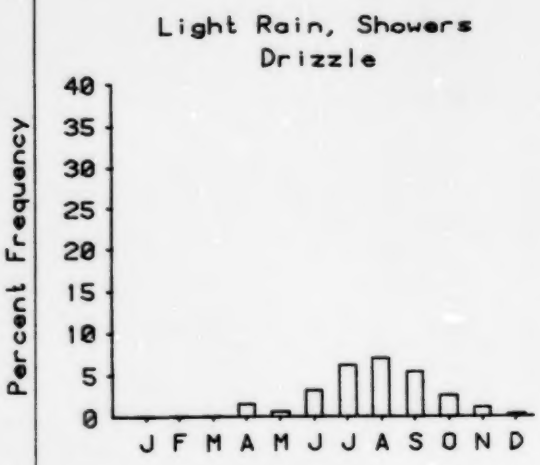
SEA SURFACE TEMPERATURE

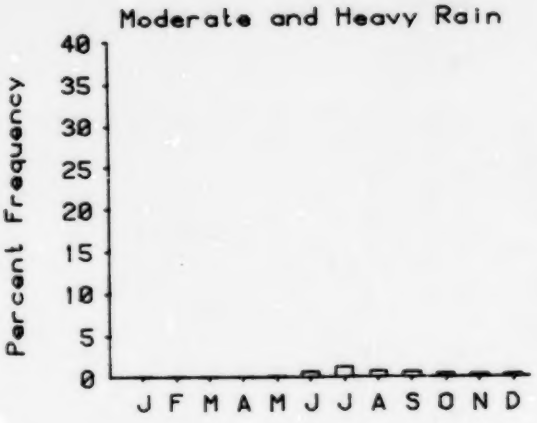
DAVIS STRAIT MARINE FORECAST AREA

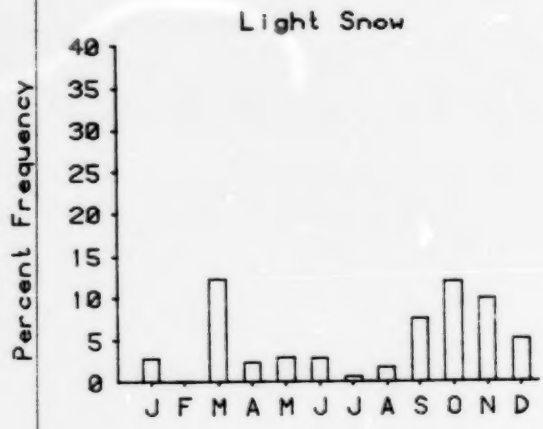


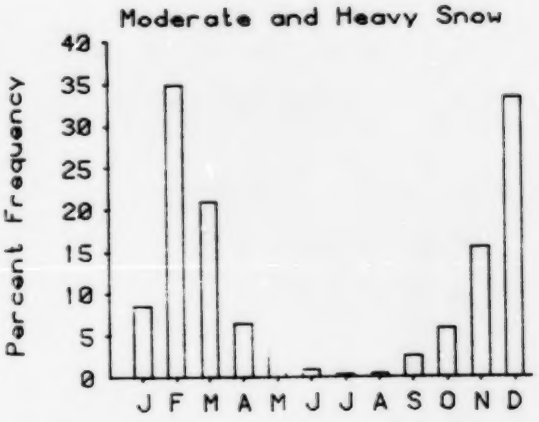
PERCENT FREQUENCY OF VISIBILITY
DAVIS STRAIT MARINE FORECAST AREA

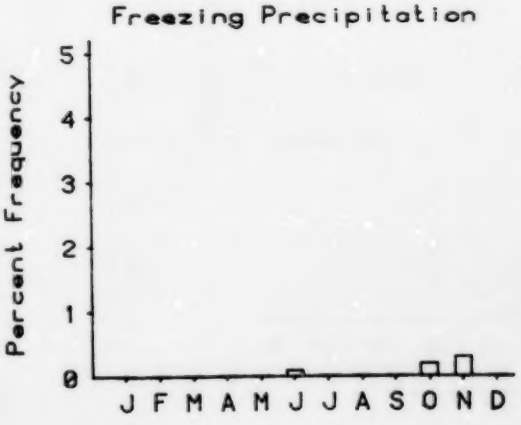
< 5.4 NAUTICAL MILES
< 2.2 NAUTICAL MILES
< 1.1 NAUTICAL MILES
< 0.5 NAUTICAL MILES



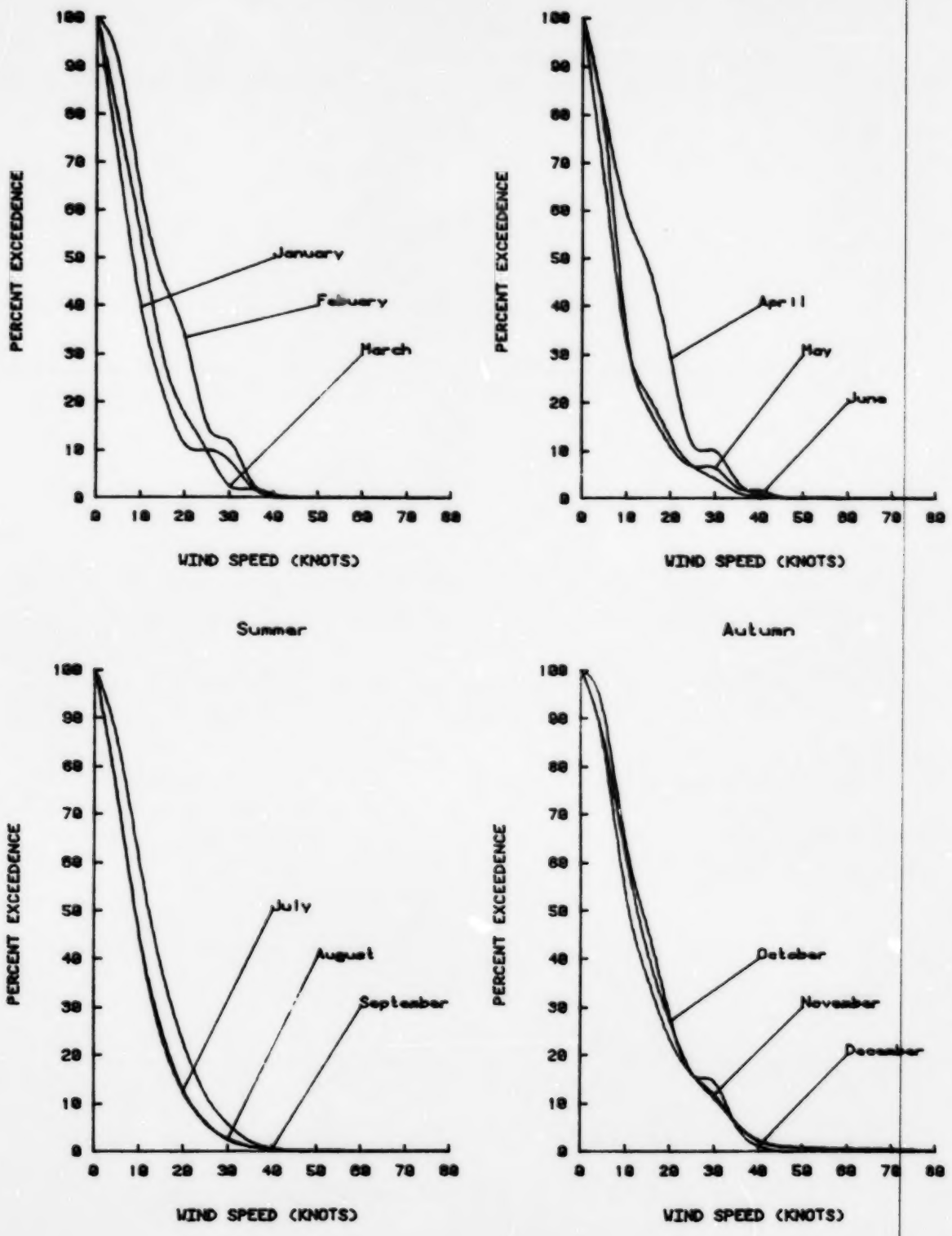




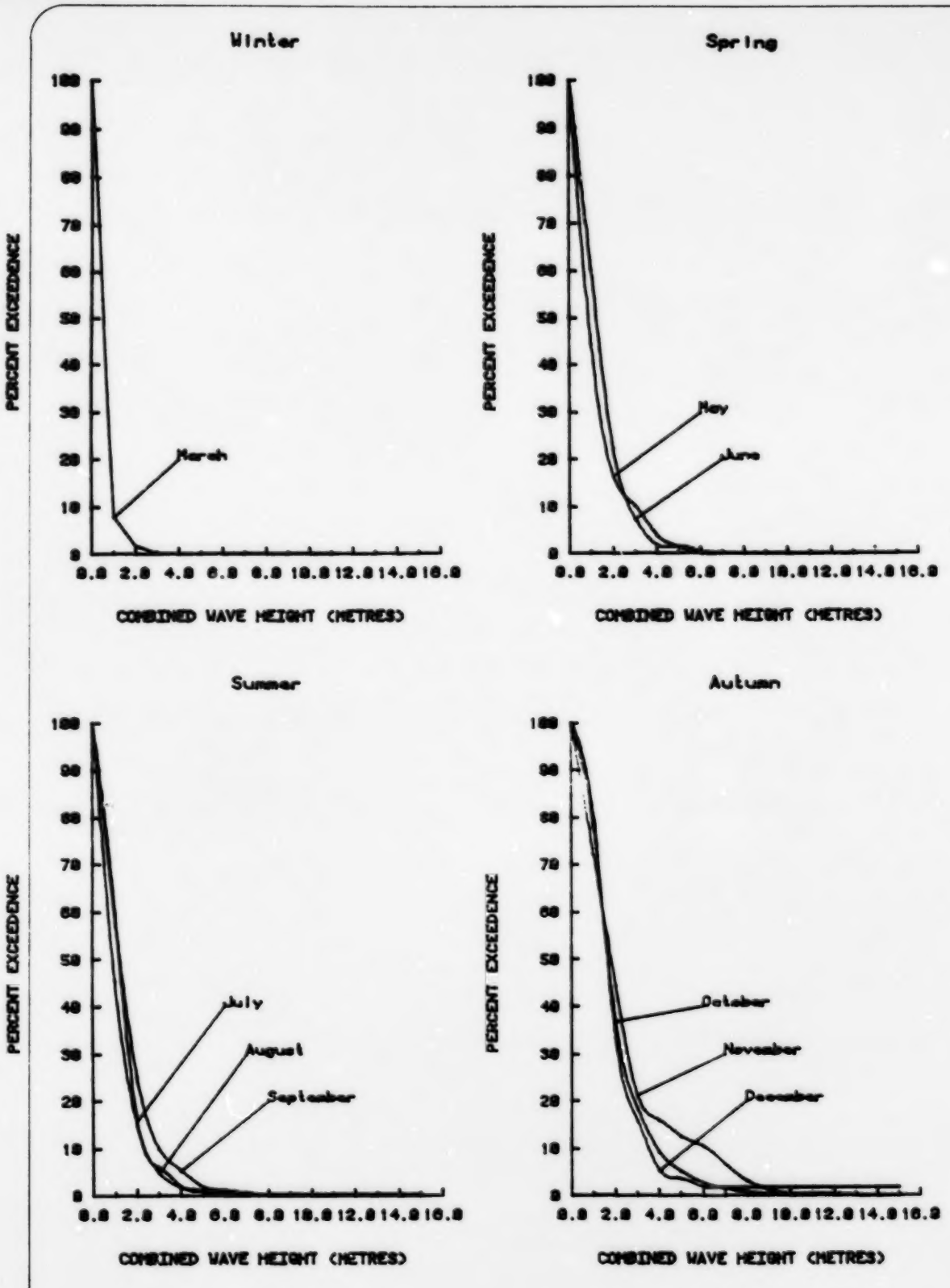




PERCENT FREQUENCY OF PRECIPITATION
DAVIS STRAIT MARINE FORECAST AREA



PERCENT EXCEEDENCE OF WIND SPEED
DAVIS STRAIT MARINE FORECAST AREA



PERCENT EXCEEDENCE OF COMBINED WAVE HEIGHT
DAVIS STRAIT MARINE FORECAST AREA

A.2 FREEZING SPRAY POTENTIAL

Tables showing the percent frequency of freezing spray potential for the nine selected AES Marine forecast areas are presented on the following pages. The results have been extracted from Atmospheric Environment Service (1984) and are based on all available marine weather observations up to 1981 using a nomogram developed by Kachurin et al (1974). With inputs of air temperature, wind speed, sea surface temperature, wave height, and salinity (set constant equal to 35 parts per thousand), the nomogram is used to obtain the theoretical icing rate of a cylinder placed in the spray zone. The output includes a calibration based on actual observations of freezing spray icing on Russian trawlers. To apply this work to the waters off the Canadian East Coast, adjustments were made (Atmospheric Environment Service, 1984) using the results of trawler icing records as published by Stallabrass (1980). The derived data on freezing spray potential are presented under the following severity criteria:

Light	0-3 cm/24 hours
Moderate	3-6 cm/24 hours
Heavy	6-14 cm/24 hours
Severe	14+ cm/24 hours

Care must be exercised when using these data for northern waters where the statistics are based on a relatively smaller data set and where the presence of pack ice limits wave development and, consequently reduces the risk of freezing spray accretion.

GEORGES BANK

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
LIGHT	3.5	3.7	1.4	-	-	-	-	-	-	-	0.1	1.1
MODERATE	0.1	1.0	0.1	-	-	-	-	-	-	-	-	0.2
HEAVY	-	1.6	-	-	-	-	-	-	-	-	-	0.1
SEVERE	-	-	-	-	-	-	-	-	-	-	-	-

SABLE

LIGHT	10.5	12.4	5.8	0.6	-	-	-	-	-	-	0.1	4.7
MODERATE	2.3	5.0	1.2	-	-	-	-	-	-	-	-	1.0
HEAVY	1.6	2.6	0.7	-	-	-	-	-	-	-	-	0.4
SEVERE	1.1	0.1	-	-	-	-	-	-	-	-	-	-

BANQUEREAU BANK

LIGHT	10.9	15.9	7.4	1.4	-	-	-	-	-	-	-	3.8
MODERATE	2.3	5.6	1.7	0.1	-	-	-	-	-	-	-	0.4
HEAVY	2.4	3.6	1.8	-	-	-	-	-	-	-	-	0.3
SEVERE	-	-	-	-	-	-	-	-	-	-	-	0.2

GULF MAGDALEN

LIGHT	19.1	26.9	12.4	4.9	-	-	-	-	-	0.2	2.1	12.7
MODERATE	9.9	10.3	7.2	-	-	-	-	-	-	-	0.2	5.1
HEAVY	7.6	1.3	3.1	-	-	-	-	-	-	-	-	4.7
SEVERE	-	2.6	-	-	-	-	-	-	-	-	-	-

PERCENT FREQUENCY OF FREEZING SPRAY POTENTIAL

NORTHERN GRAND BANKS

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
LIGHT	9.5	13.7	5.2	2.2	-	-	-	-	-	-	0.2	5.6
MODERATE	2.3	3.1	0.7	-	-	-	-	-	-	-	0.1	0.9
HEAVY	1.3	2.6	0.1	0.1	-	-	-	-	-	-	-	0.4
SEVERE	-	0.1	-	-	-	-	-	-	-	-	-	-

BELLE ISLE BANK

LIGHT	18.6	17.6	10.5	0.1	-	-	-	-	-	0.1	4.0	16.9
MODERATE	10.7	11.3	3.1	2.3	-	-	-	-	-	-	0.4	3.5
HEAVY	12.2	10.1	3.0	0.3	-	-	-	-	-	-	0.3	1.8
SEVERE	1.0	0.5	0.2	-	-	-	-	-	-	-	-	0.1

NORTHWEST LABRADOR SEA

LIGHT	17.4	-	13.8	15.2	-	-	-	-	-	2.0	18.1	23.3
MODERATE	28.3	44.4	3.4	7.4	-	-	-	-	-	-	4.4	17.8
HEAVY	21.7	-	-	0.5	-	-	-	-	-	-	1.1	22.2
SEVERE	4.3	-	-	-	-	-	-	-	-	-	-	2.2

DAVIS STRAIT

LIGHT	-	-	7.1	14.3	2.0	0.6	0.1	-	0.4	7.1	18.5	10.6
MODERATE	-	-	-	21.4	-	-	-	-	-	0.6	13.7	21.3
HEAVY	66.7	-	57.1	-	-	-	-	-	-	0.4	4.0	25.5
SEVERE	-	-	-	-	-	-	-	-	-	-	-	-

SOUTHEASTERN GRAND BANKS

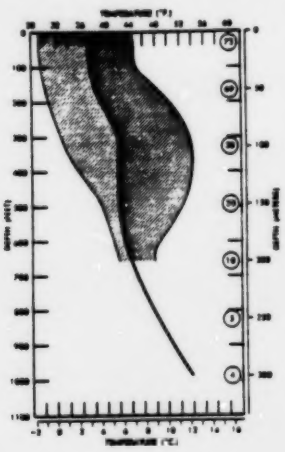
LIGHT	5.1	7.0	3.5	0.2	-	-	-	-	-	-	-	1.8
MODERATE	1.6	2.1	0.1	0.1	-	-	-	-	-	-	-	-
HEAVY	-	0.8	0.1	-	-	-	-	-	-	-	-	-
SEVERE	-	-	-	-	-	-	-	-	-	-	-	-

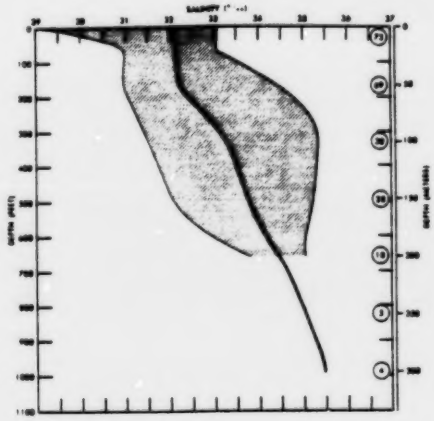
PERCENT FREQUENCY OF FREEZING SPRAY POTENTIAL (CONTINUED)

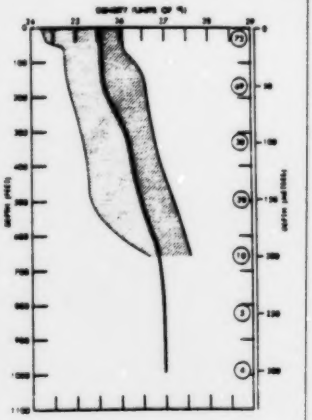
A.3 TYPICAL TRACES AND RANGE OF TEMPERATURE, SALINITY, AND DENSITY

The following five figures show typical traces and ranges of temperature, salinity, and density for the Canadian East Coast shelf waters for the months of February, May, August, and November. These figures are drawn from U.S. Naval Oceanographic Office (1967).

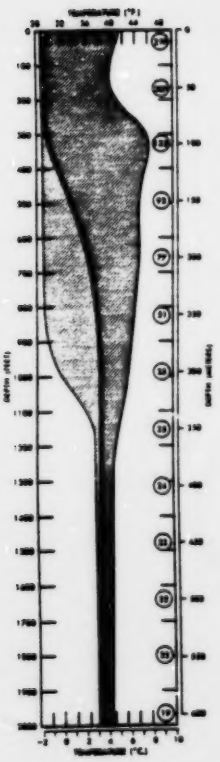
FEBRUARY

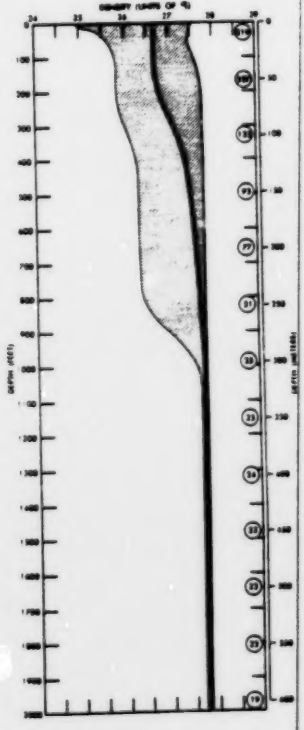






SCOTIAN SHELF



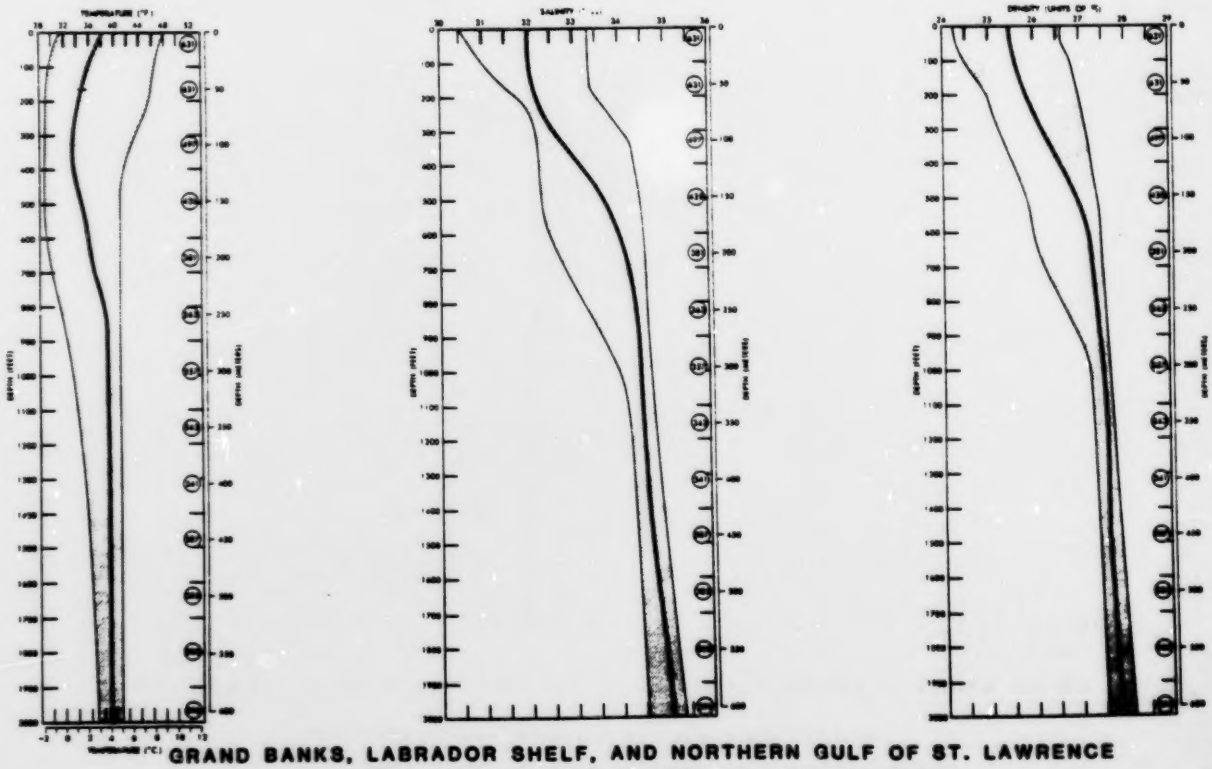


GRAND BANKS AND LABRADOR SHELF

TYPICAL TRACES AND RANGE OF TEMPERATURE, SALINITY, AND DENSITY

MAY

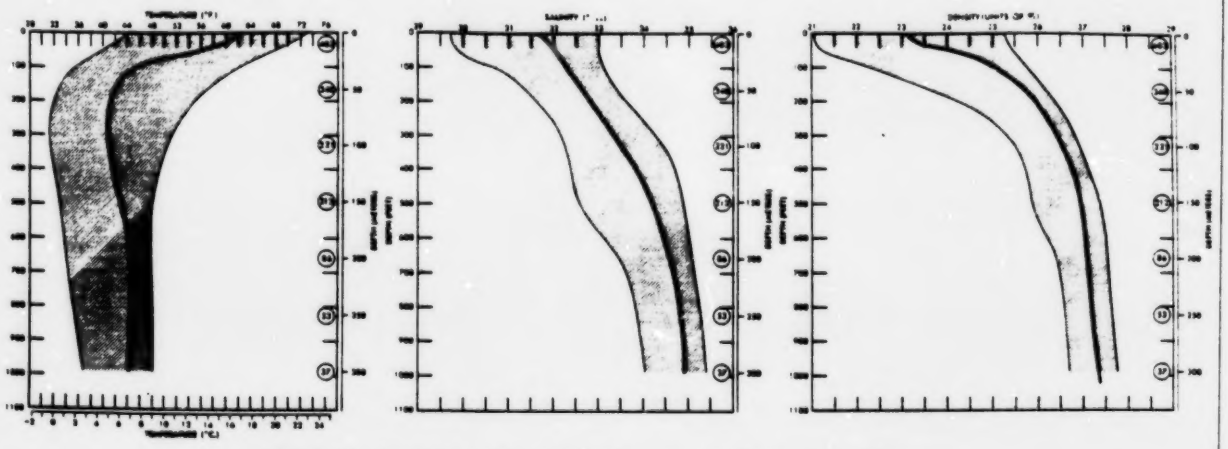
SCOTIAN SHELF AND SOUTHERN GULF OF ST. LAWRENCE



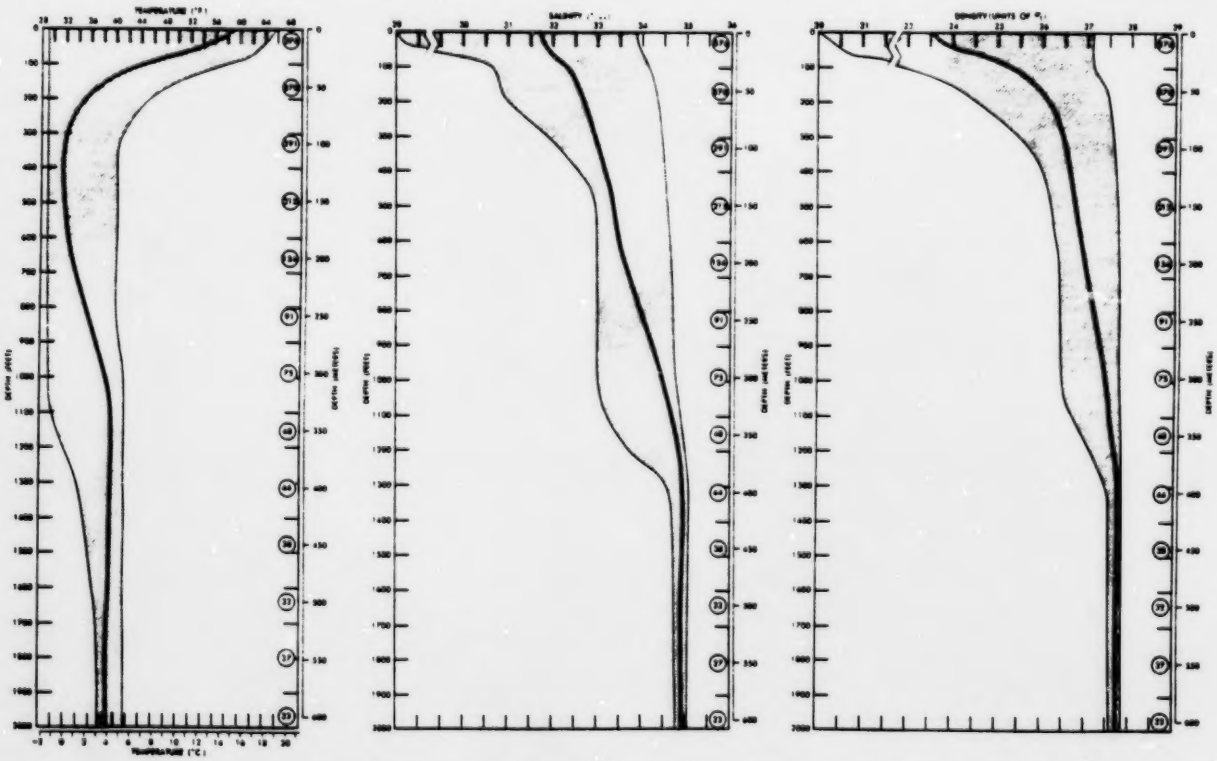
GRAND BANKS, LABRADOR SHELF, AND NORTHERN GULF OF ST. LAWRENCE

TYPICAL TRACES AND RANGE OF TEMPERATURE, SALINITY, AND DENSITY

AUGUST



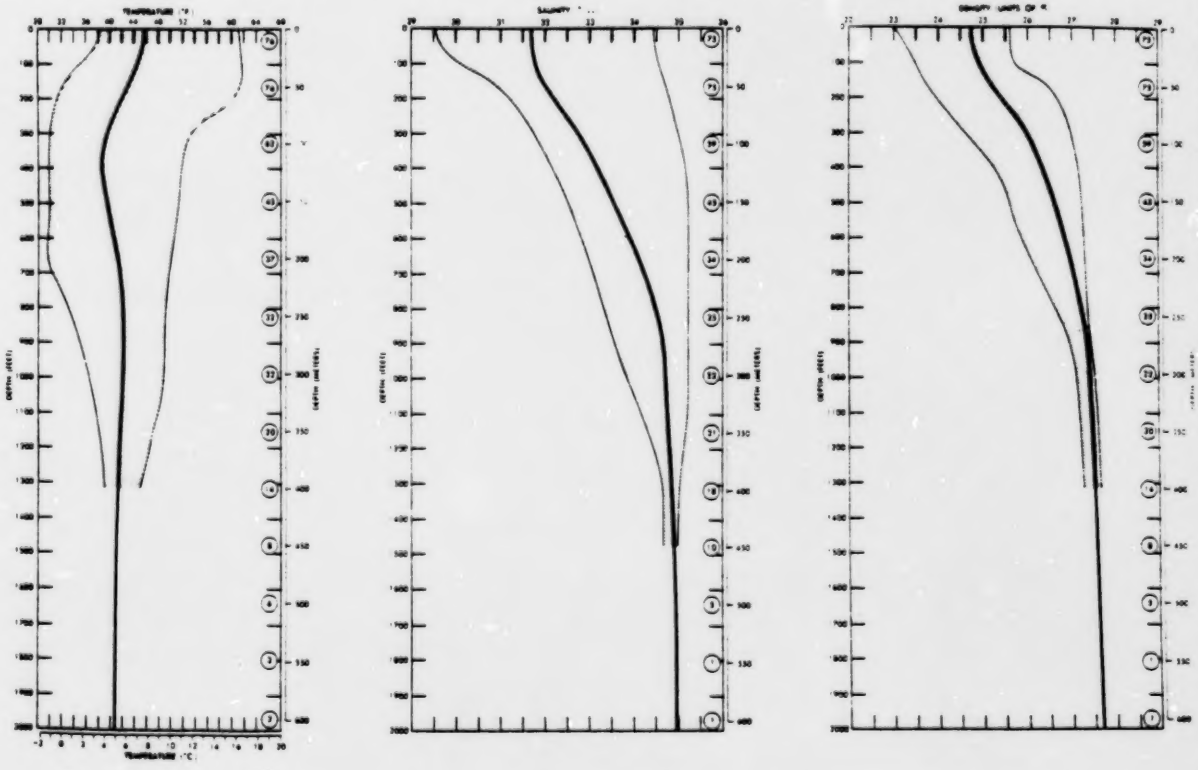
SCOTIAN SHELF AND SOUTHERN GULF OF ST LAWRENCE



GRAND BANKS , LABRADOR SHELF AND NORTHERN GULF OF ST. LAWRENCE

TYPICAL TRACES AND RANGE OF TEMPERATURE, SALINITY, AND DENSITY

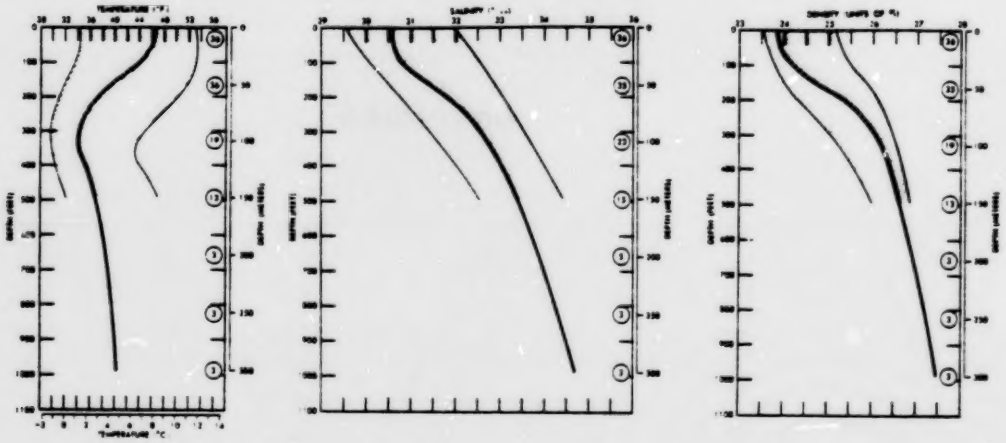
NOVEMBER



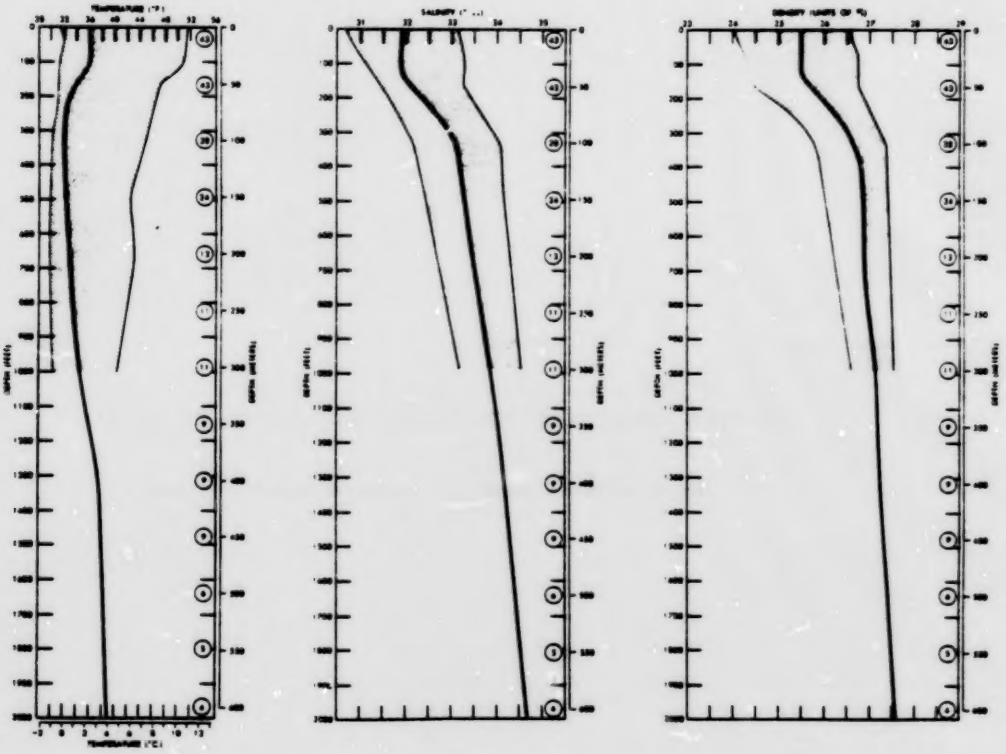
SCOTIAN SHELF AND NORTHERN GULF OF ST. LAWRENCE

TYPICAL TRACES AND RANGE OF TEMPERATURE, SALINITY, AND DENSITY

NOVEMBER



NOVA SCOTIA COASTAL WATERS AND SOUTHERN GULF OF ST. LAWRENCE



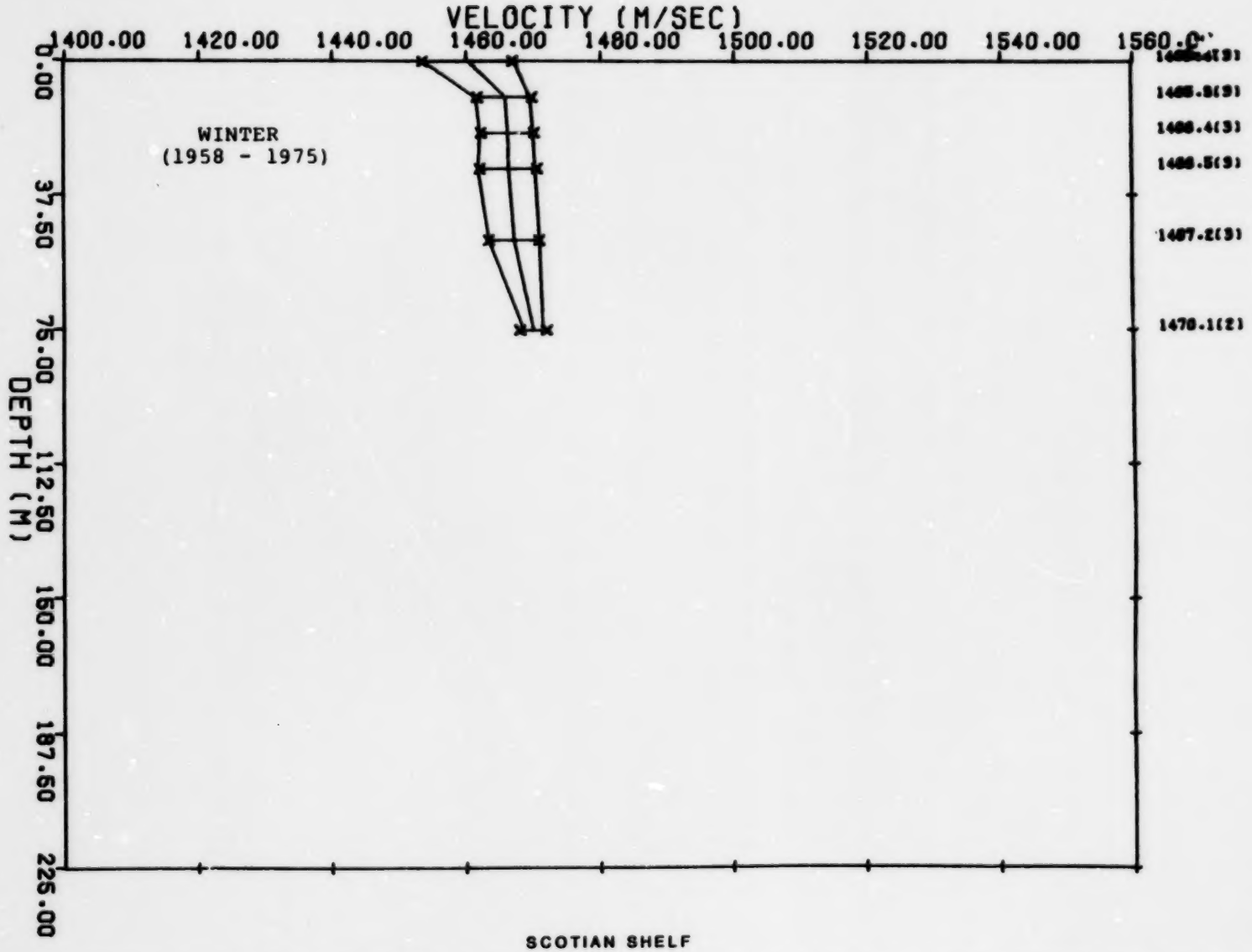
GRAND BANKS AND LABRADOR SHELF

TYPICAL TRACES AND RANGE OF TEMPERATURE, SALINITY, AND DENSITY

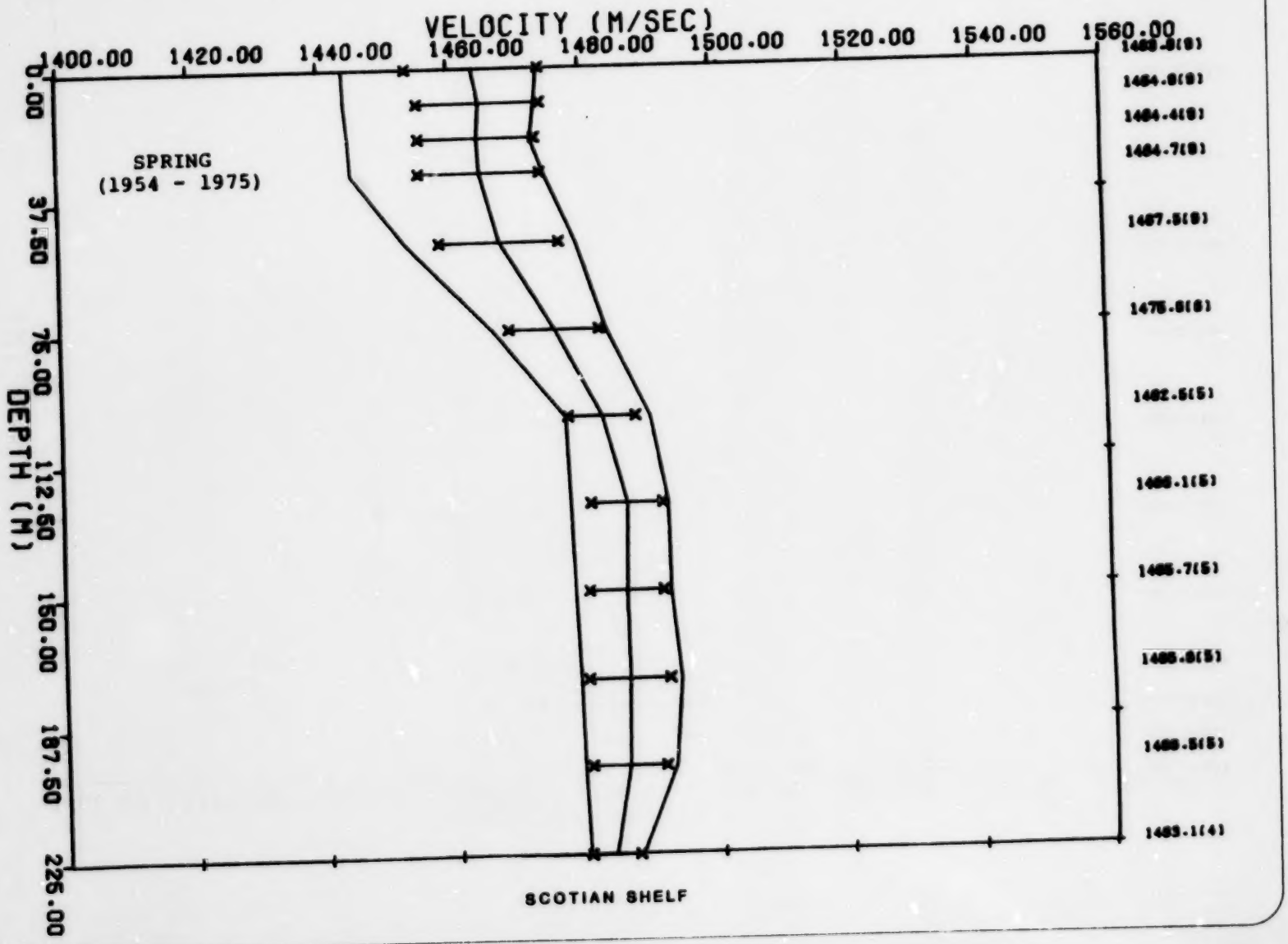
A.4 SOUND SPEED PROFILES IN EAST COAST WATERS

The accompanying diagrams taken from Scrimger (1979) show sound speed profiles in four areas off the East Coast of Canada. These areas are delineated in the table below. For each area typical profiles and ranges of sound speed are shown for the winter, spring, summer, and autumn season with one exception. There is no summary profile and range data for the winter months for the southern Labrador shelf and Northeast Newfoundland shelf due to a paucity of data. As a replacement, profile data for the month of March has been included. The period upon which the sound speed data has been calculated is indicated on each diagram.

MARINE AREA	BOUNDARY COORDINATES
Scotian Shelf	45.10N, 65.60W, 43.00N, 66.00W, 46.00N, 58.50W, 44.33N, 57.50W
Southern Grand Banks	42.67N, 49.75W, 45.25N, 54.50W, 46.42N. 52.58W, 44.75N, 48.84W
Northern Grand Banks	.44.75N, 48.83W, 46.42N, 52.58W, 47.75N, 50.17W, 46.67N, 48.00W
Southern Labrador Shelf And NE Newfoundland Shelf	48.75N, 52.33W, 55.00N, 57.00W, 55.00N, 52.00W, 48.75N, 49.33W



NORDCO LIMITED



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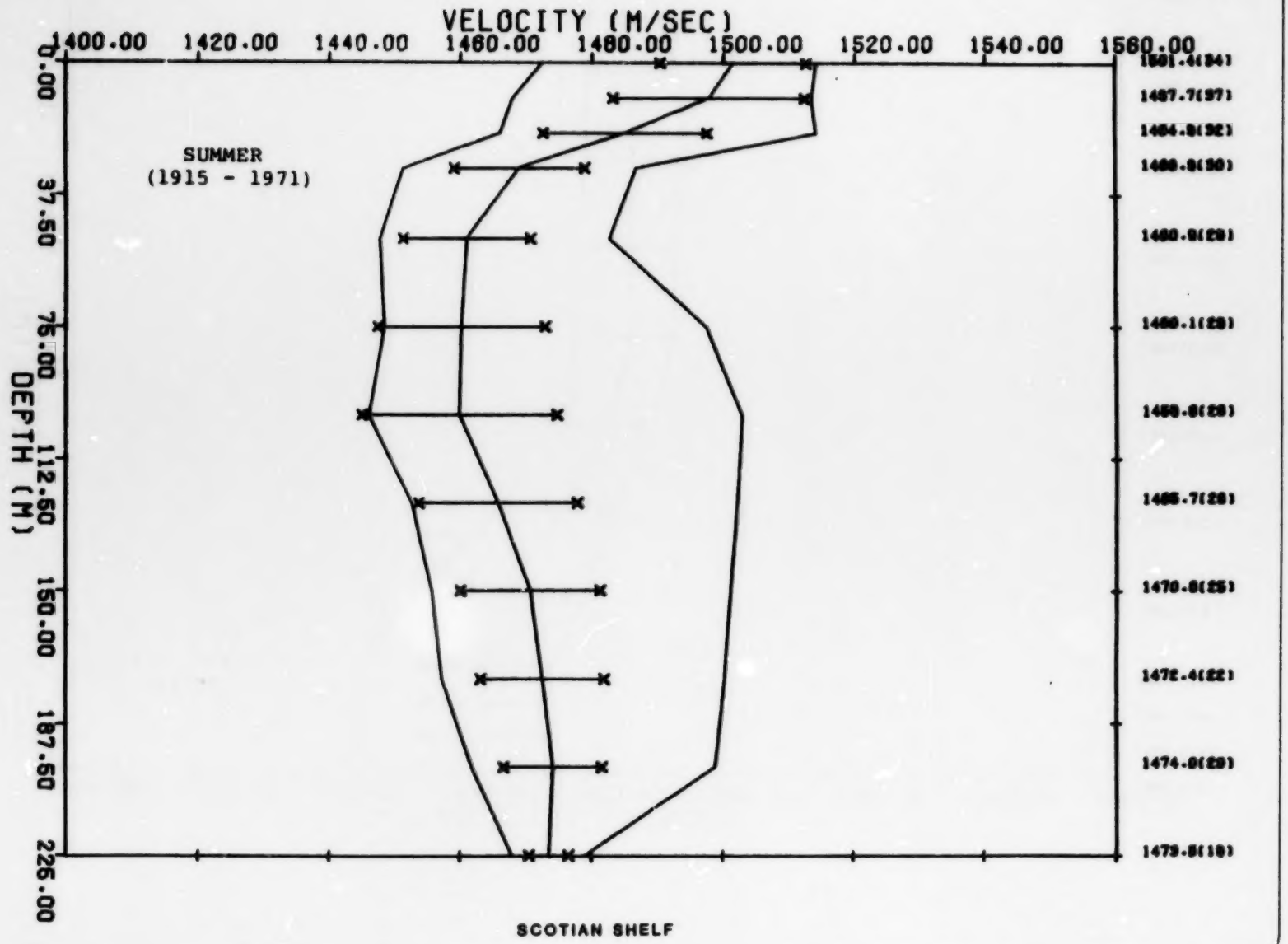
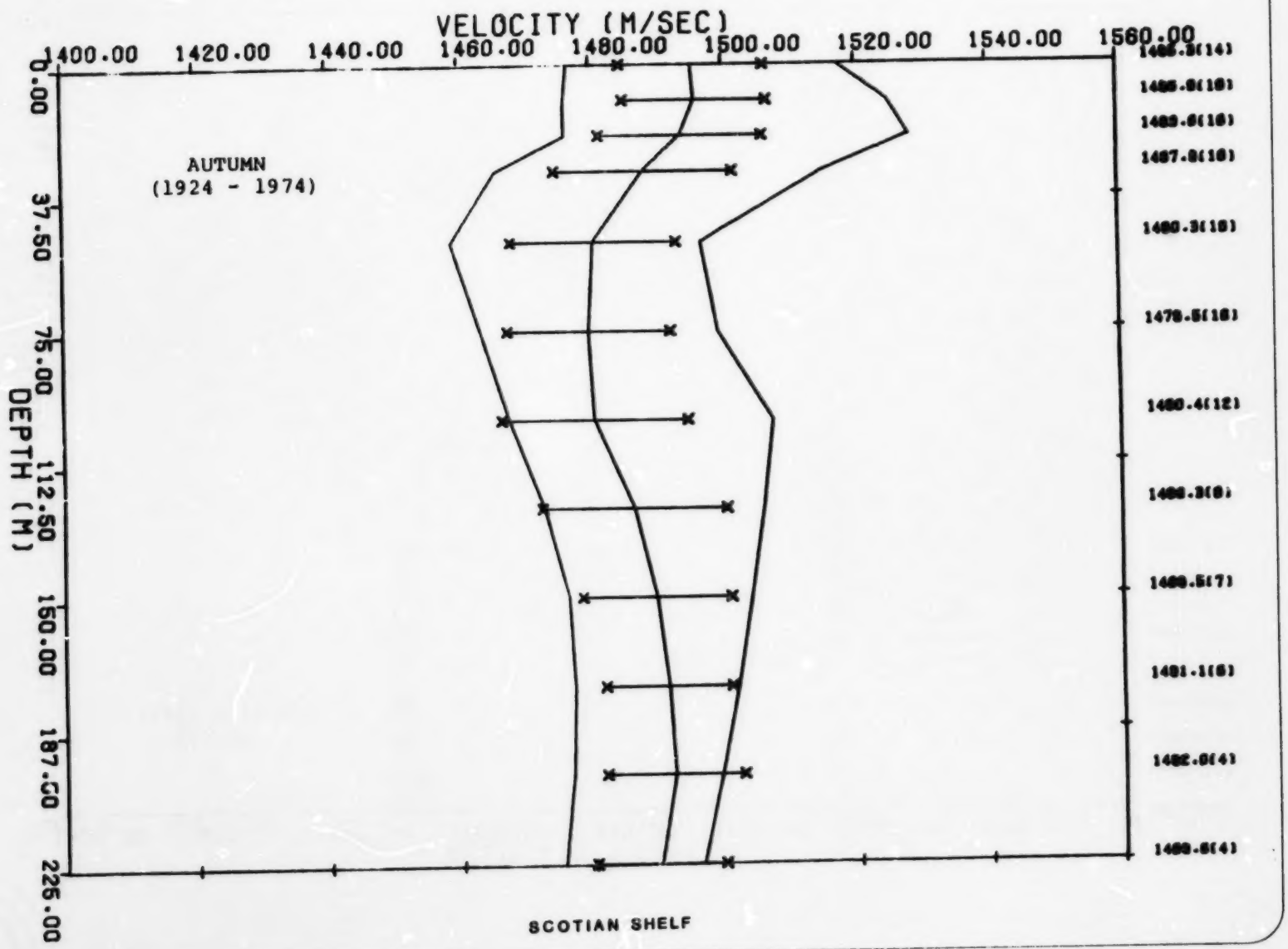


NORDCO LIMITED



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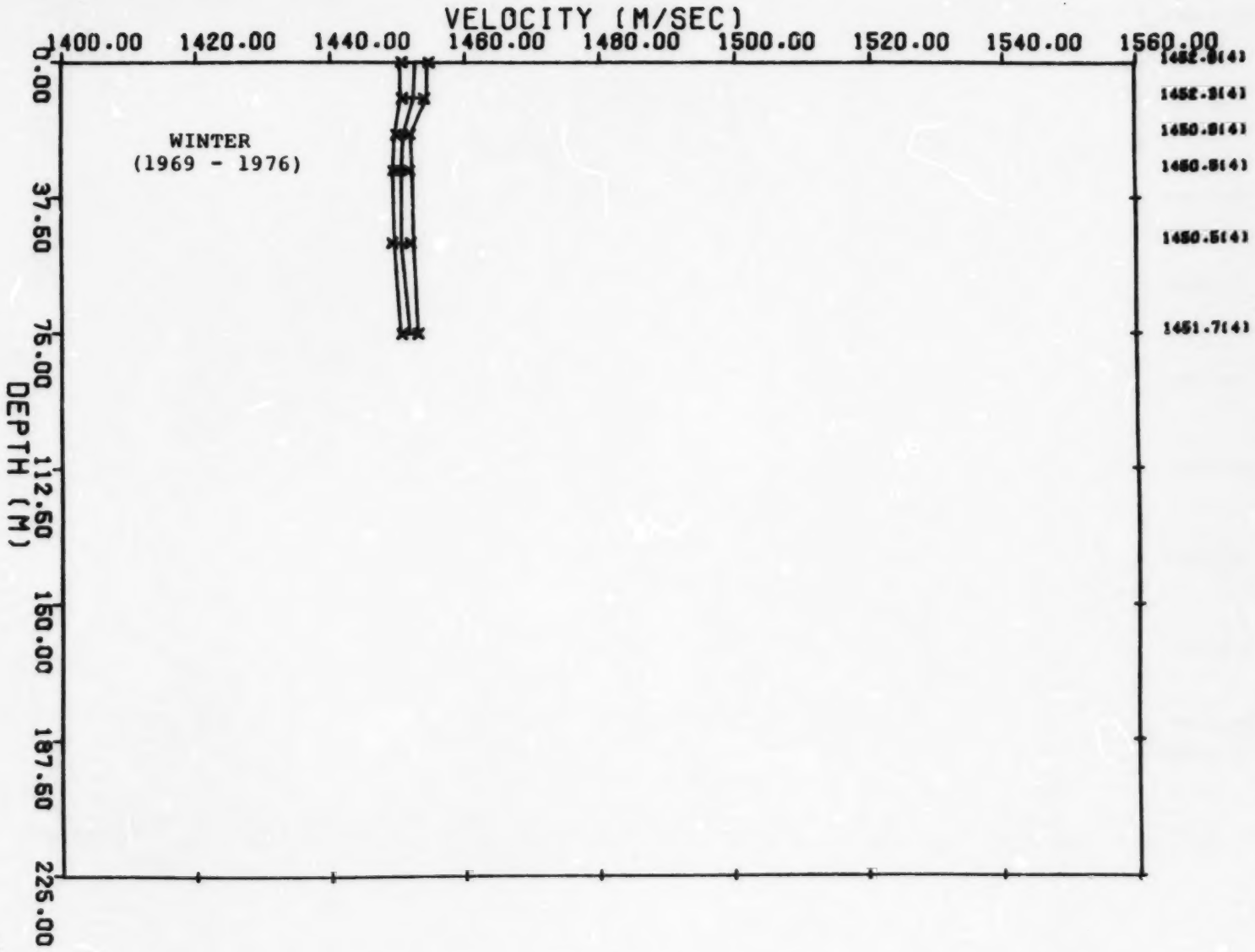
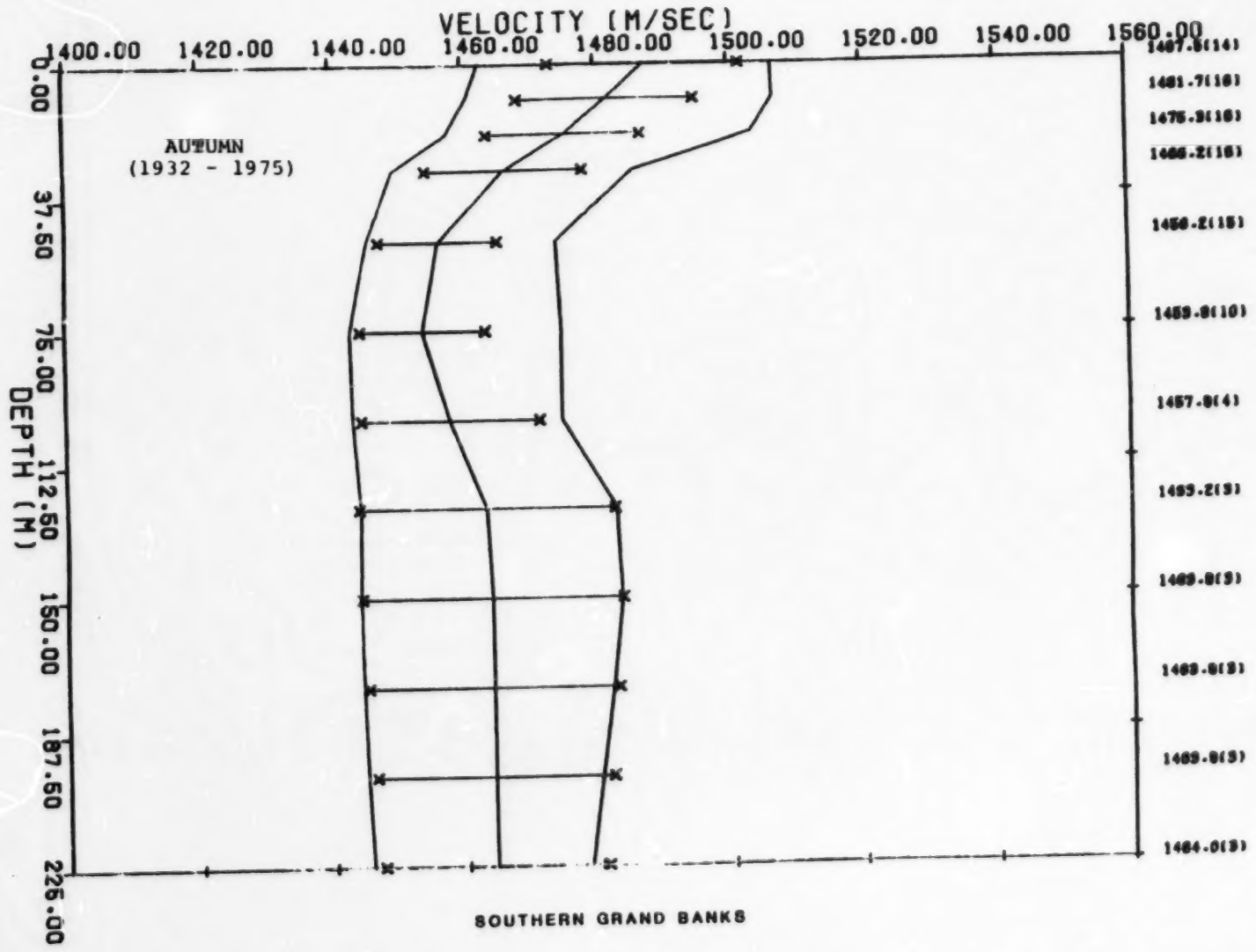


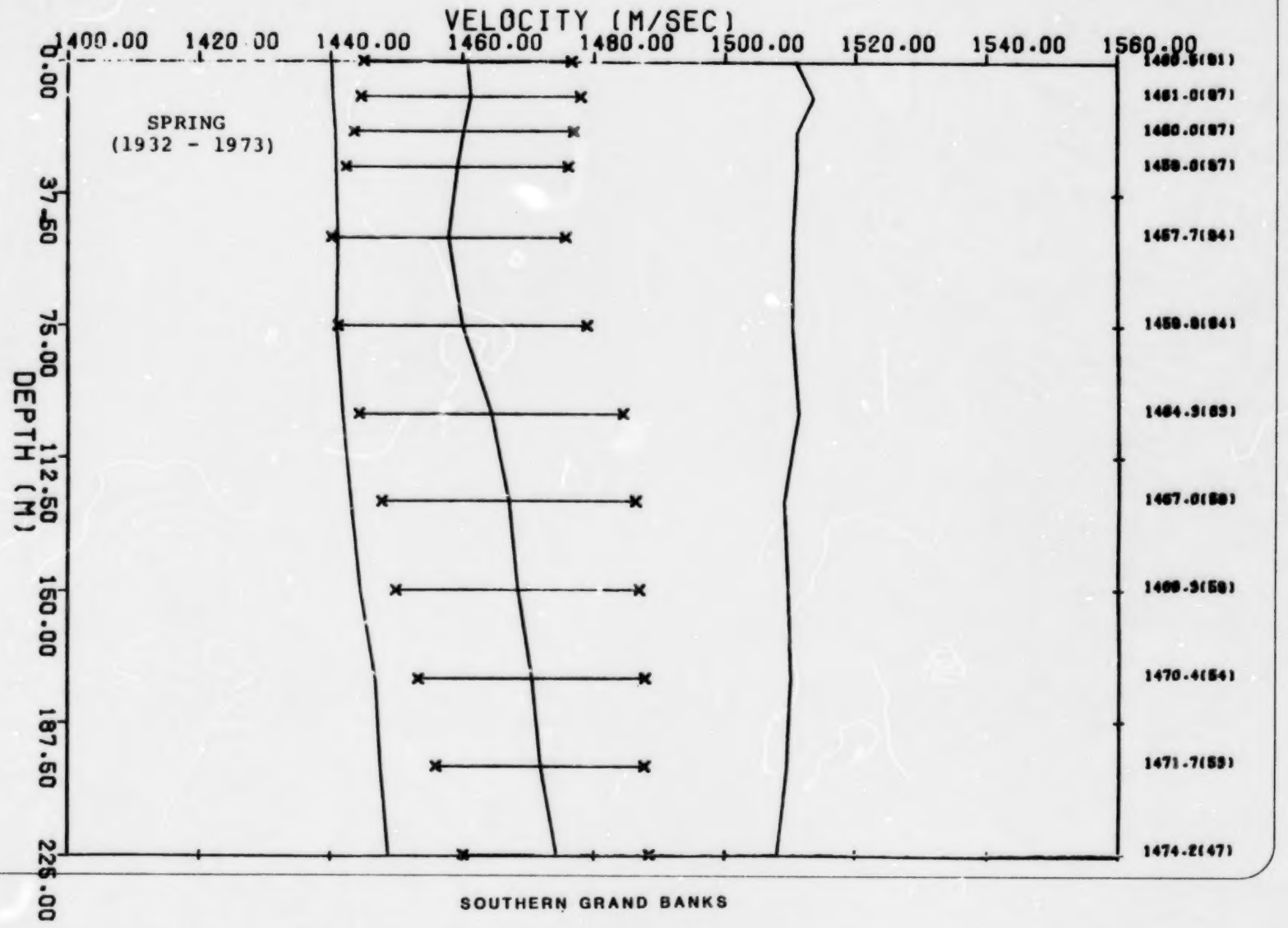
SOUTHERN GRAND BANKS

NORDCO LIMITED

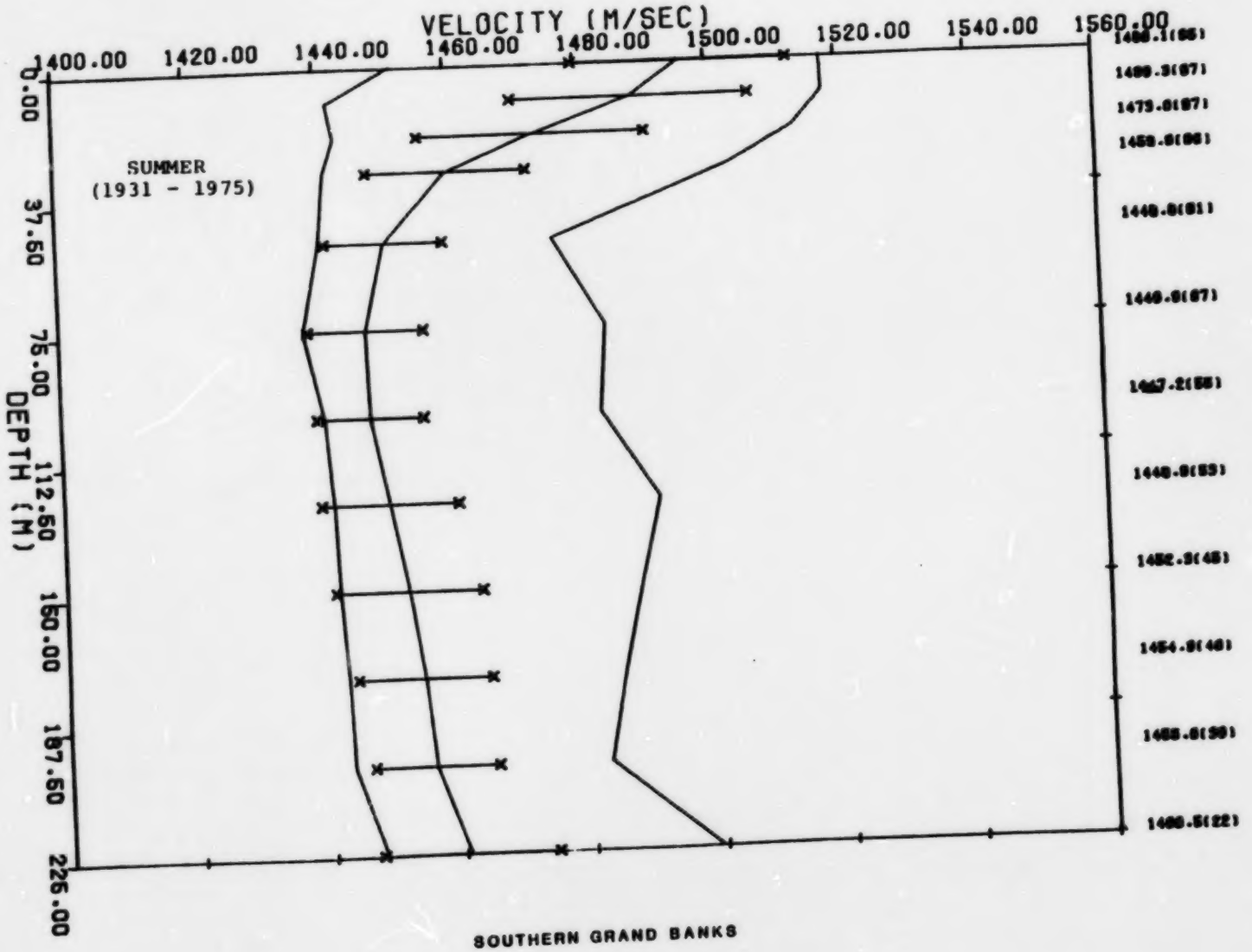


SOUTHERN GRAND BANKS

NORDCO LIMITED



NORDCO LIMITED



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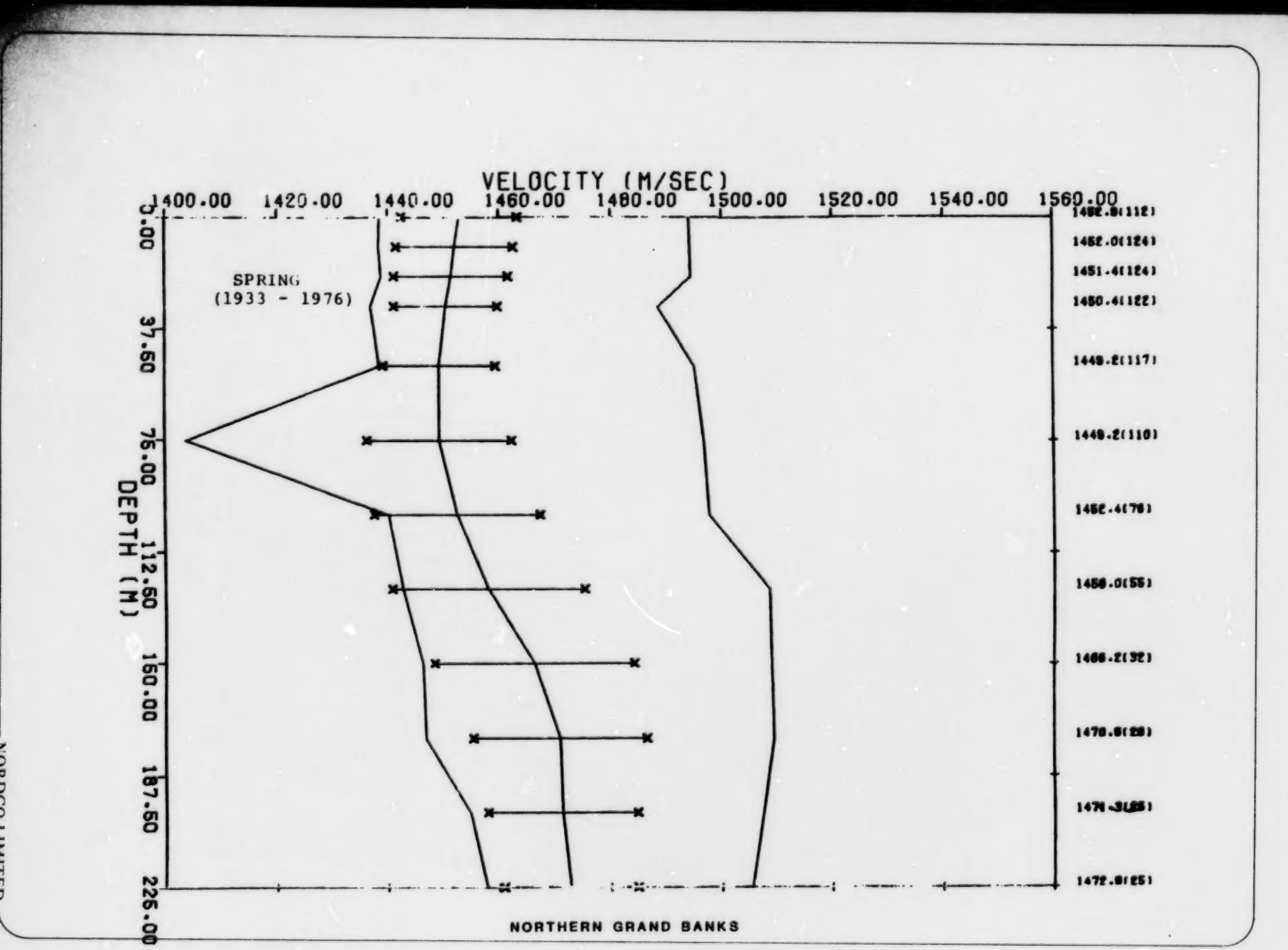
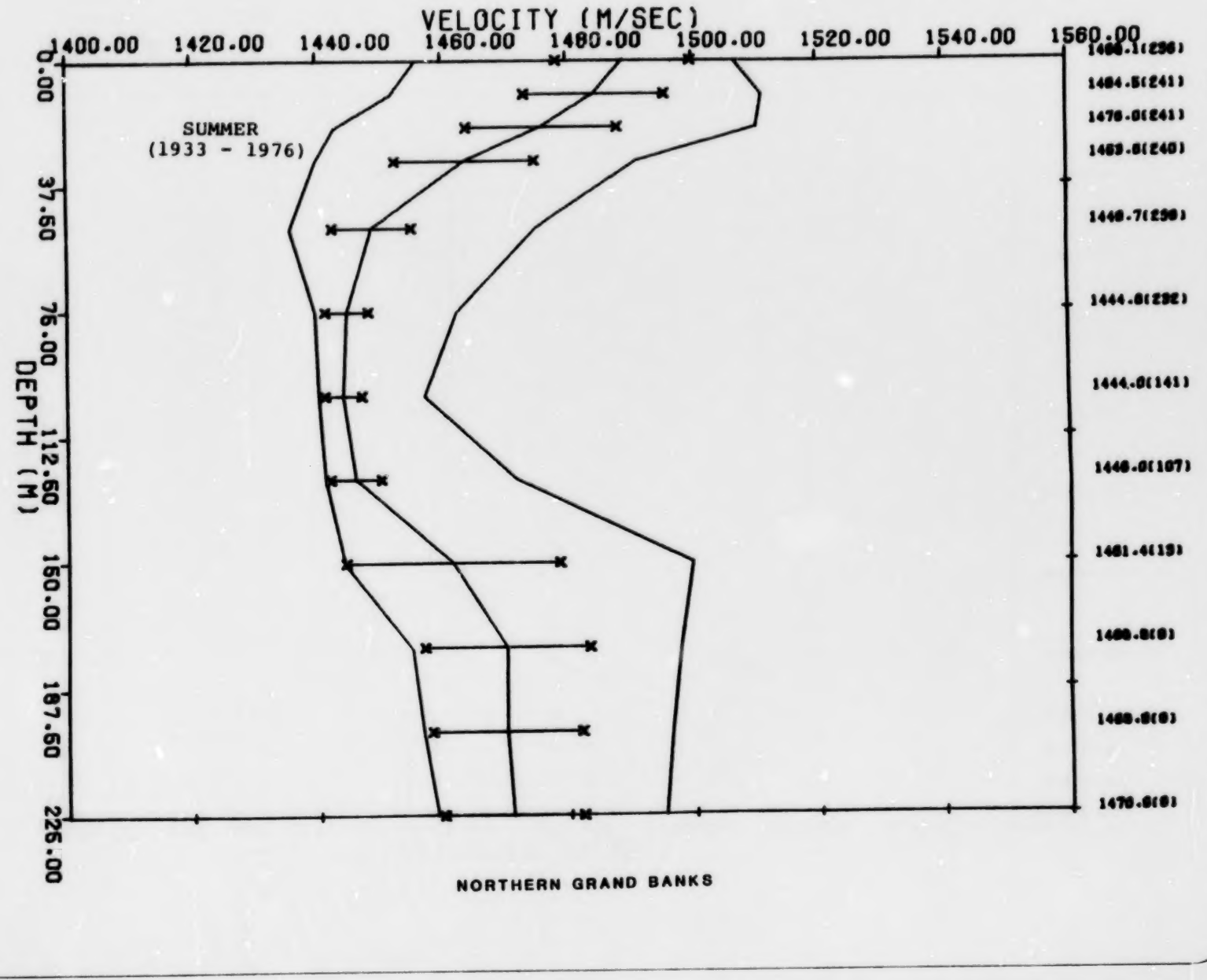
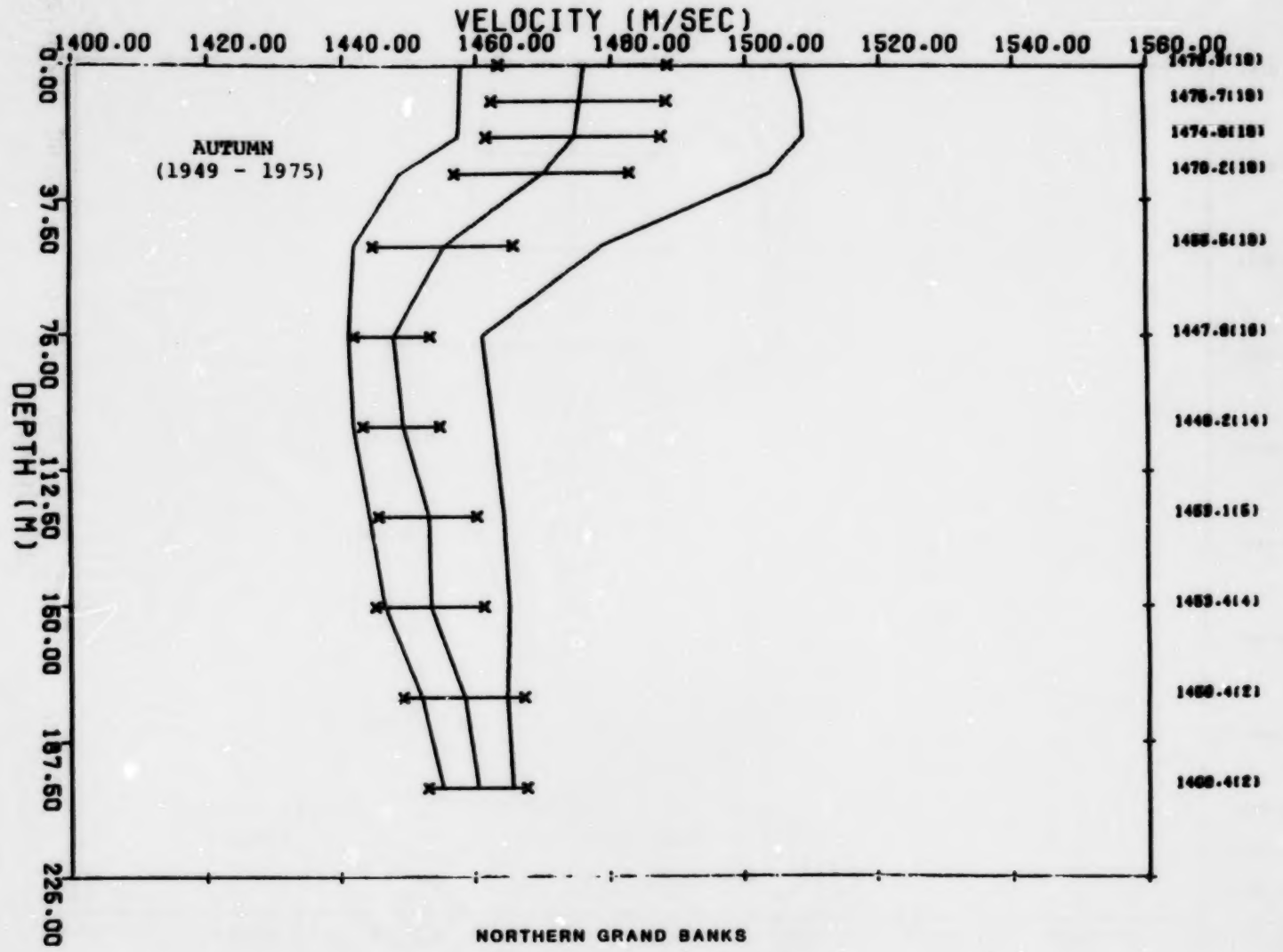
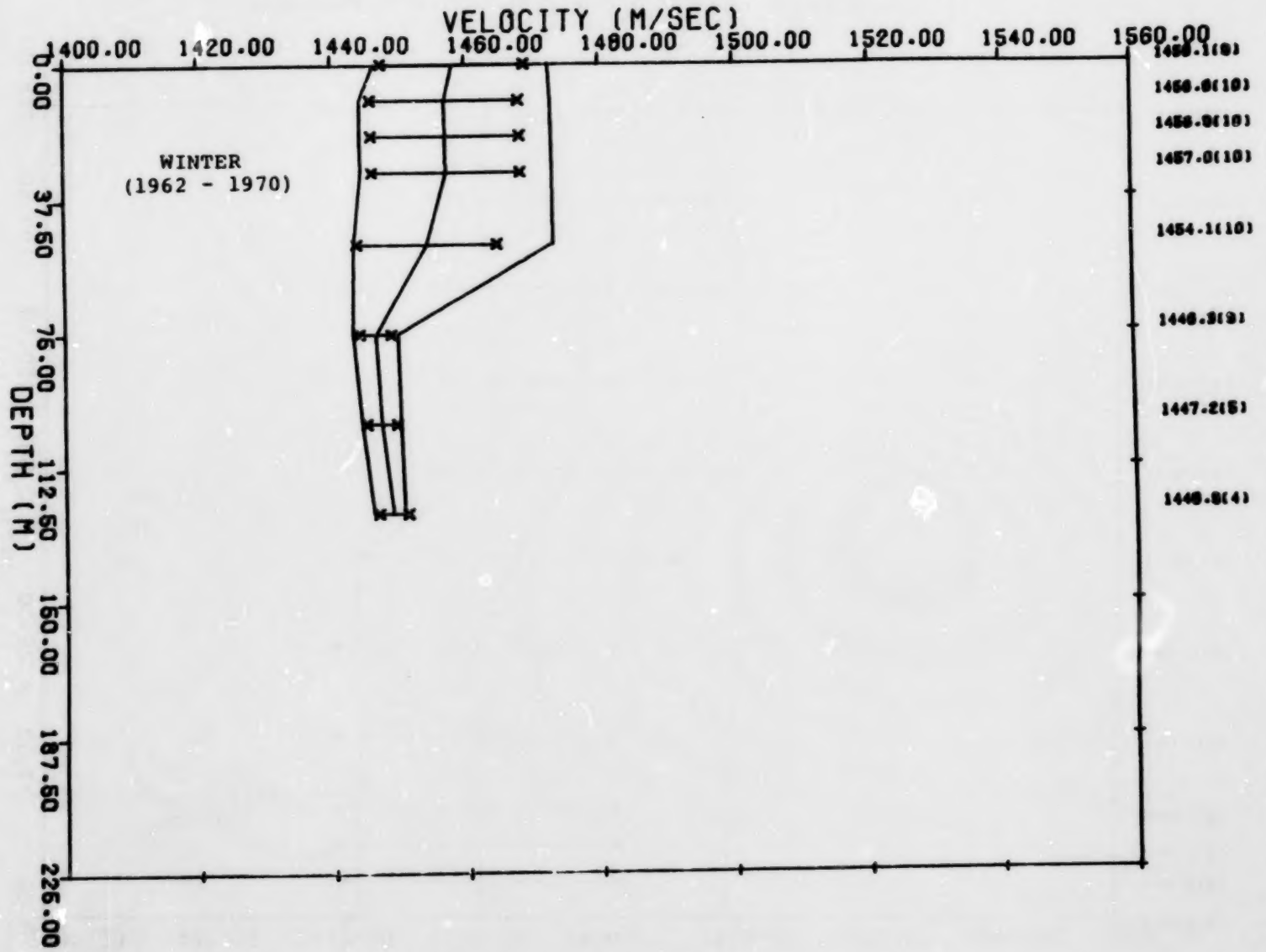
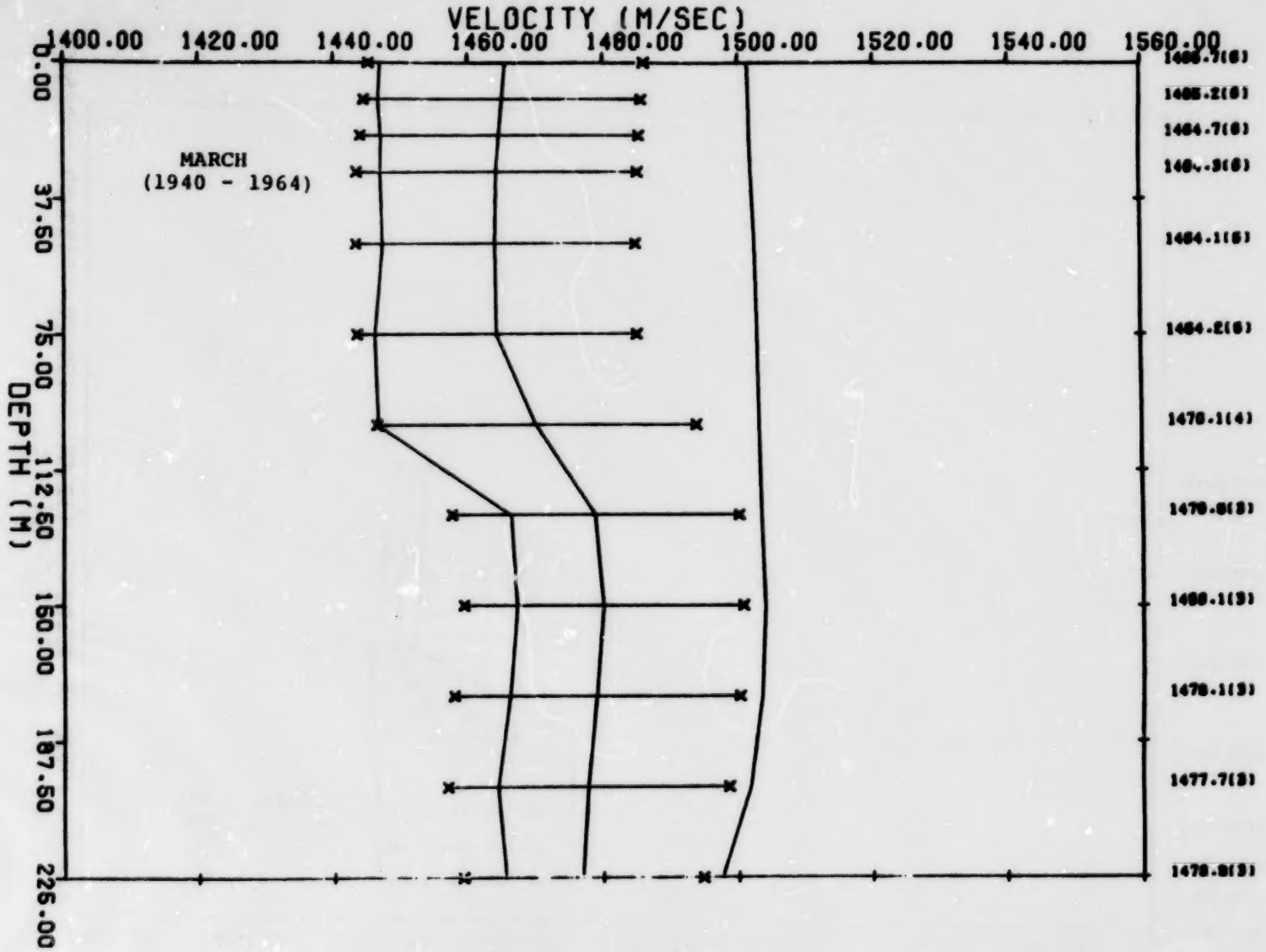

VELOCITY (M/SEC)
1400.00
1420.00
1440.00
1460.00
1480.00
1500.00
1520.00
1540.00
1560.00
SPRING
(1933 - 1976)
DEPTH (M)
0.00
37.50
75.00
112.50
150.00
187.50
225.00
1452.0(124)
1451.4(124)
1450.4(122)
1449.2(117)
1449.2(110)
1452.4(78)
1458.0(55)
1466.2(32)
1470.8(28)
1472.8(25)
NORTHERN GRAND BANKS


VELOCITY (M/SEC)
1400.00
1420.00
1440.00
1460.00
1480.00
1500.00
1520.00
1540.00
1560.00
SUMMER
(1933 - 1976)
DEPTH (M)
0.00
37.50
76.00
112.50
150.00
187.50
225.00
1484.5(241)
1476.0(241)
1468.8(240)
1468.7(236)
1444.8(232)
1444.0(141)
1446.0(107)
1481.4(13)
1476.0(0)
NORTHERN GRAND BANKS

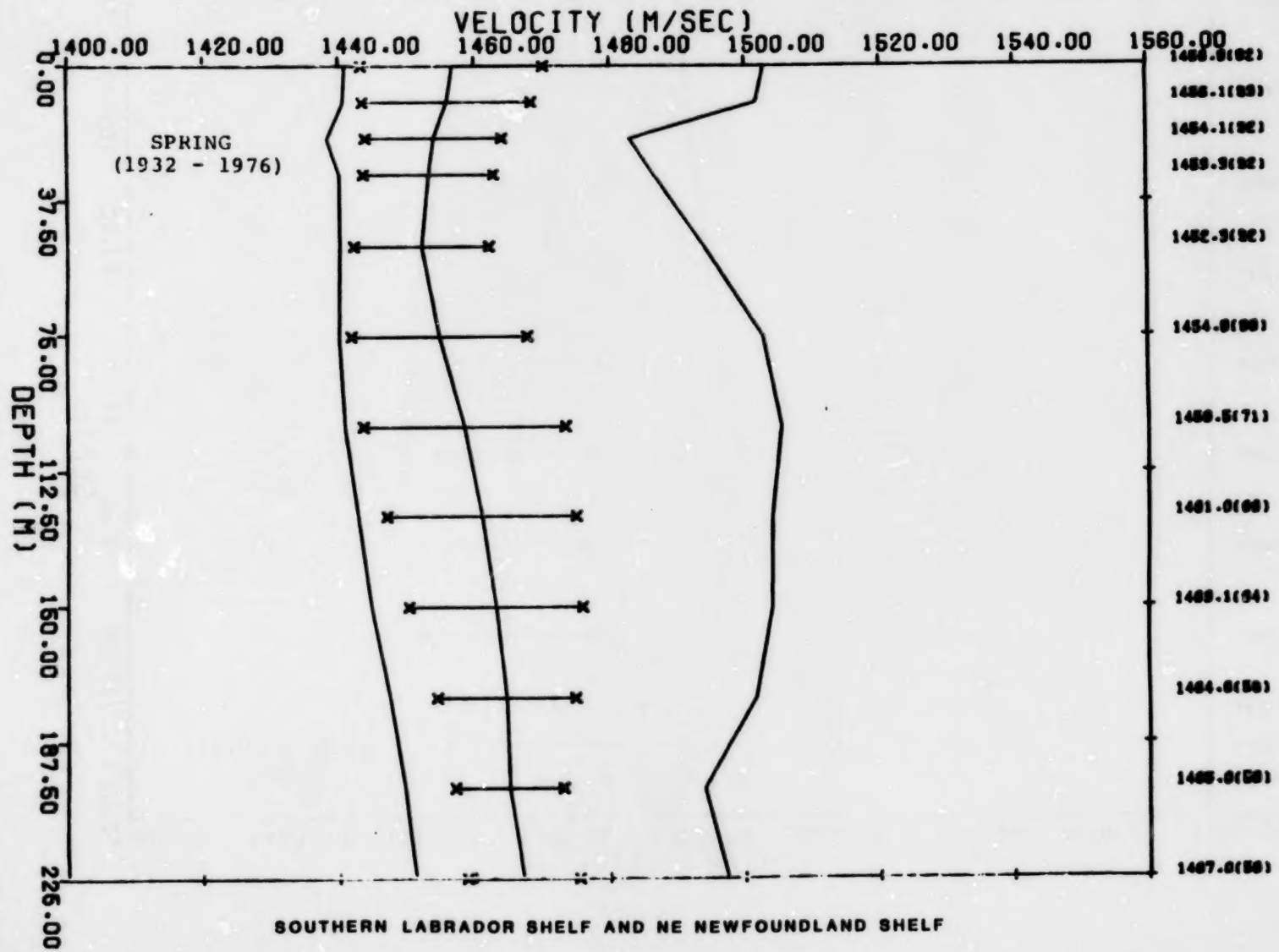

VELOCITY (M/SEC)
1400.00
1420.00
1440.00
1460.00
1480.00
1500.00
1520.00
1540.00
1560.00
0.00
37.50
75.00
112.50
150.00
187.50
225.00
DEPTH (M)
AUTUMN
(1949 - 1975)
1478.7(18)
1474.8(18)
1470.2(18)
1466.6(18)
1447.8(18)
1448.2(14)
1459.1(6)
1459.4(4)
1460.4(2)
1460.4(2)
NORTHERN GRAND BANKS



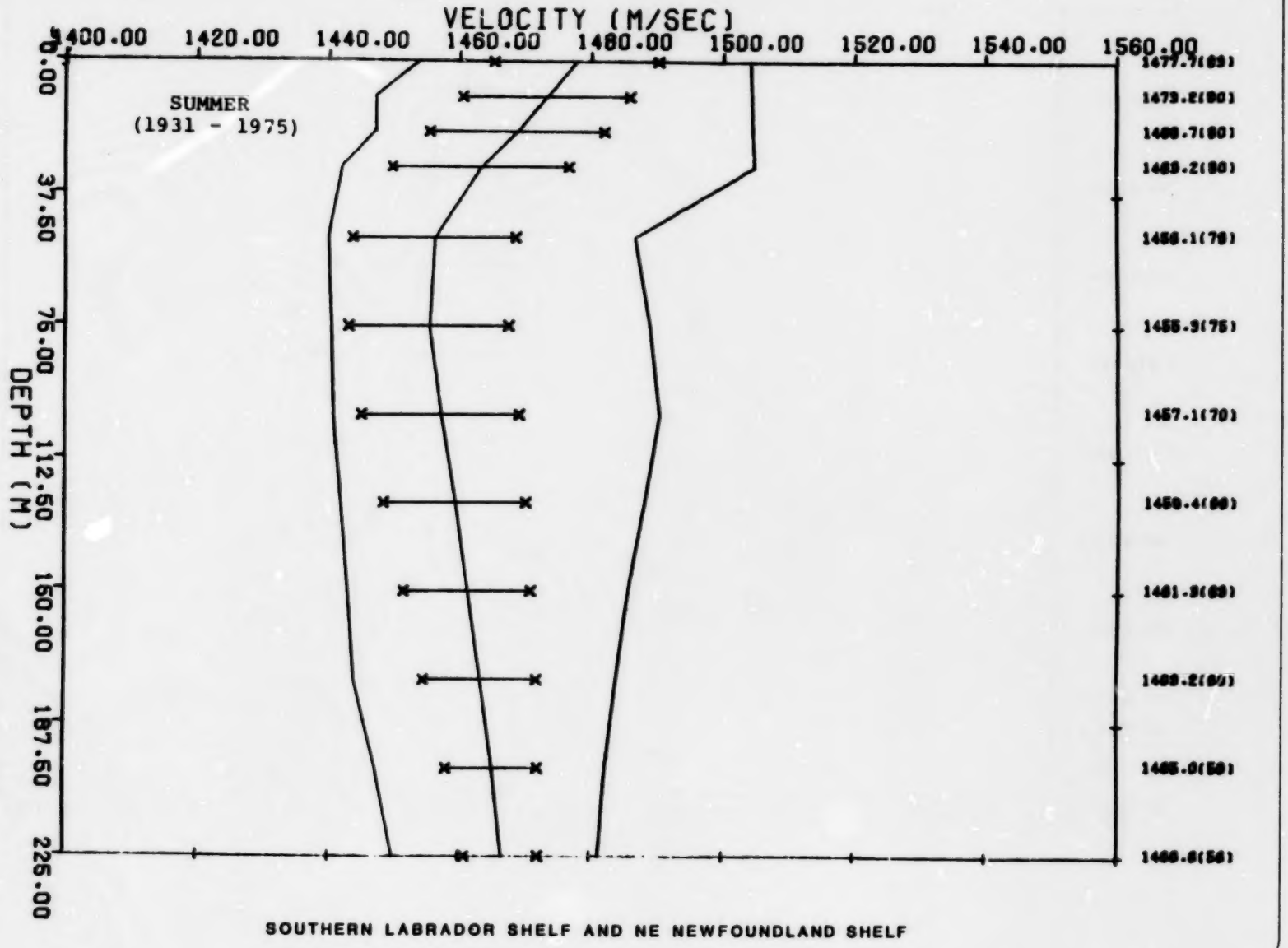
NORTHERN GRAND BANKS



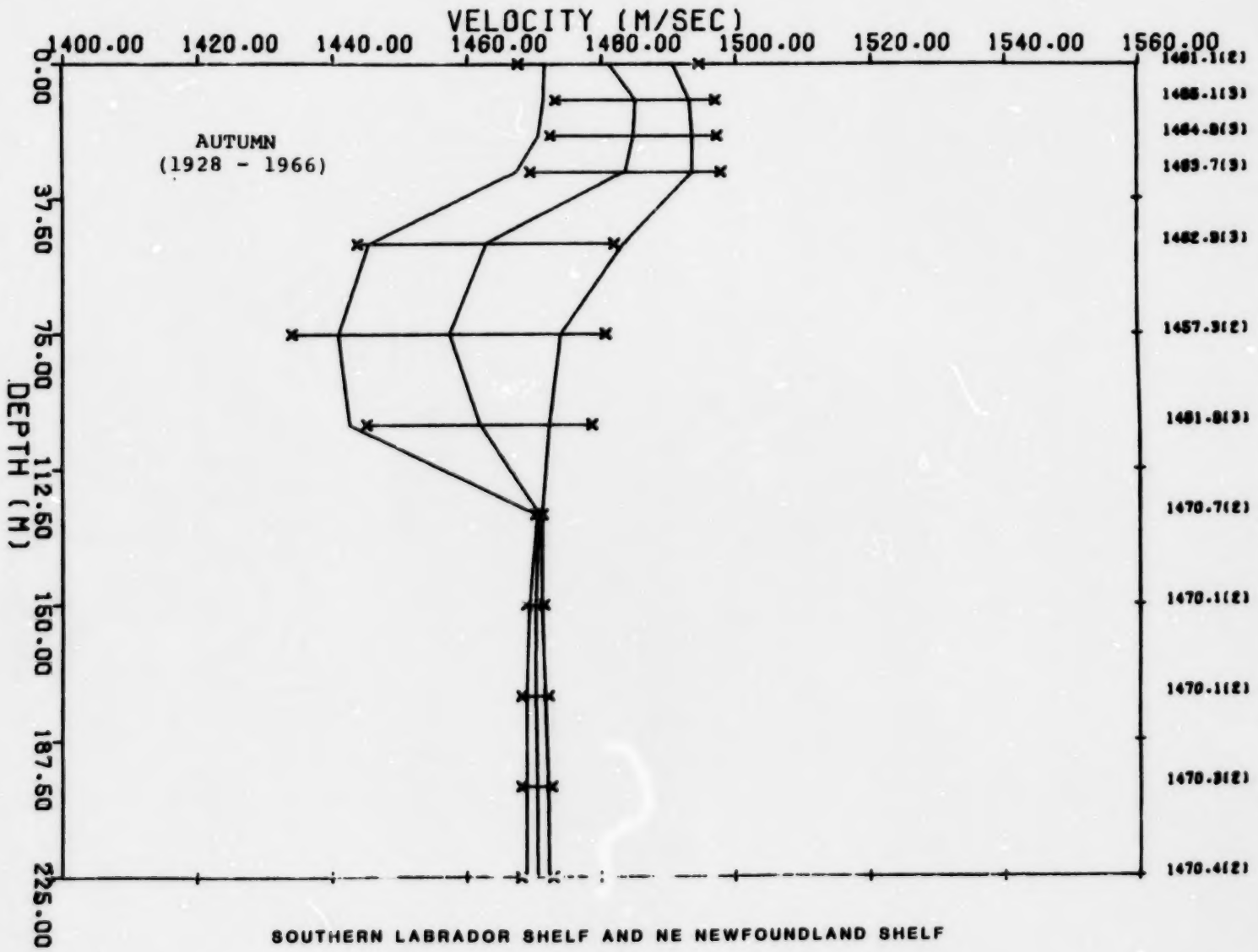
SOUTHERN LABRADOR SHELF AND NE NEWFOUNDLAND SHELF



SOUTHERN LABRADOR SHELF AND NE NEWFOUNDLAND SHELF



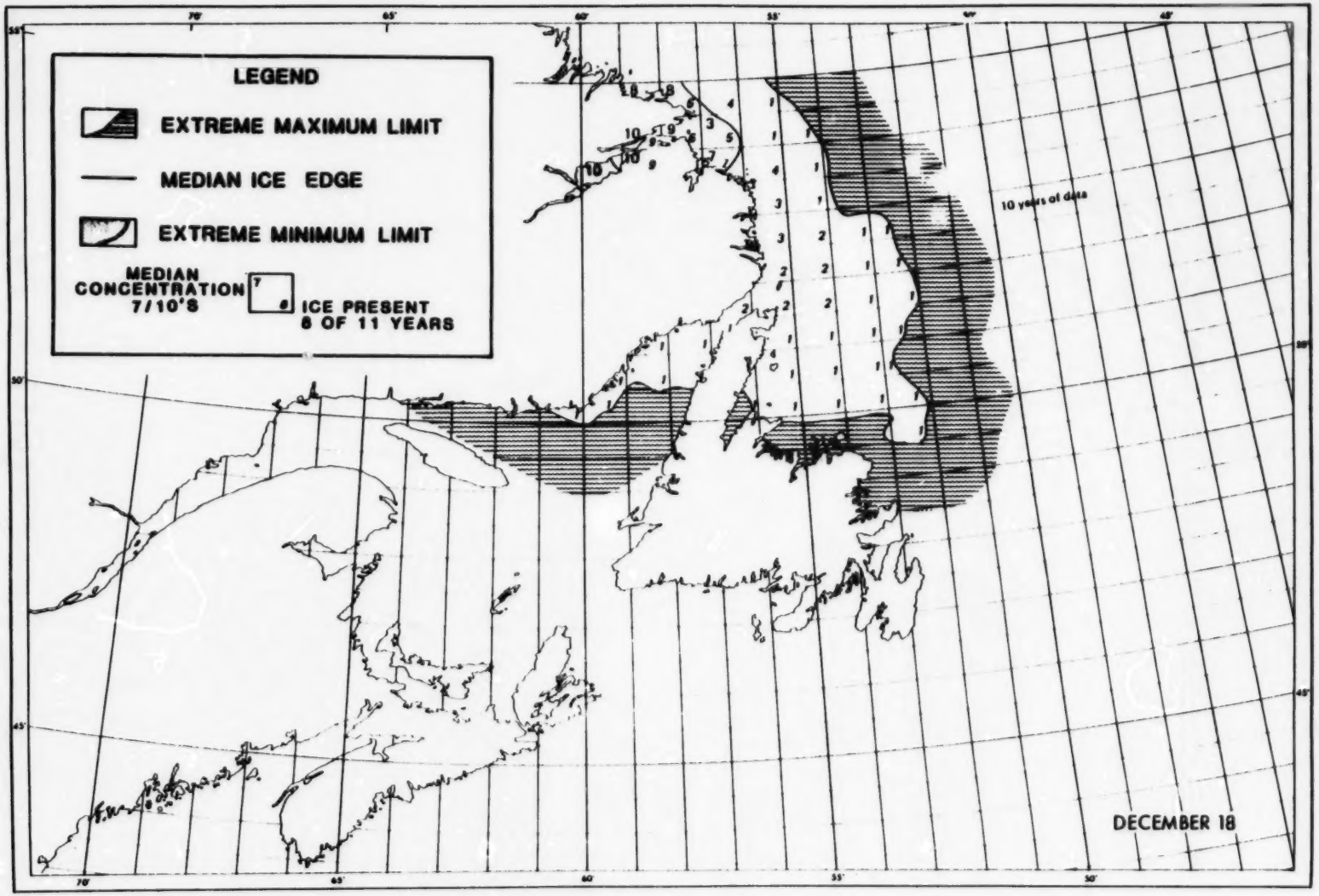
SOUTHERN LABRADOR SHELF AND NE NEWFOUNDLAND SHELF



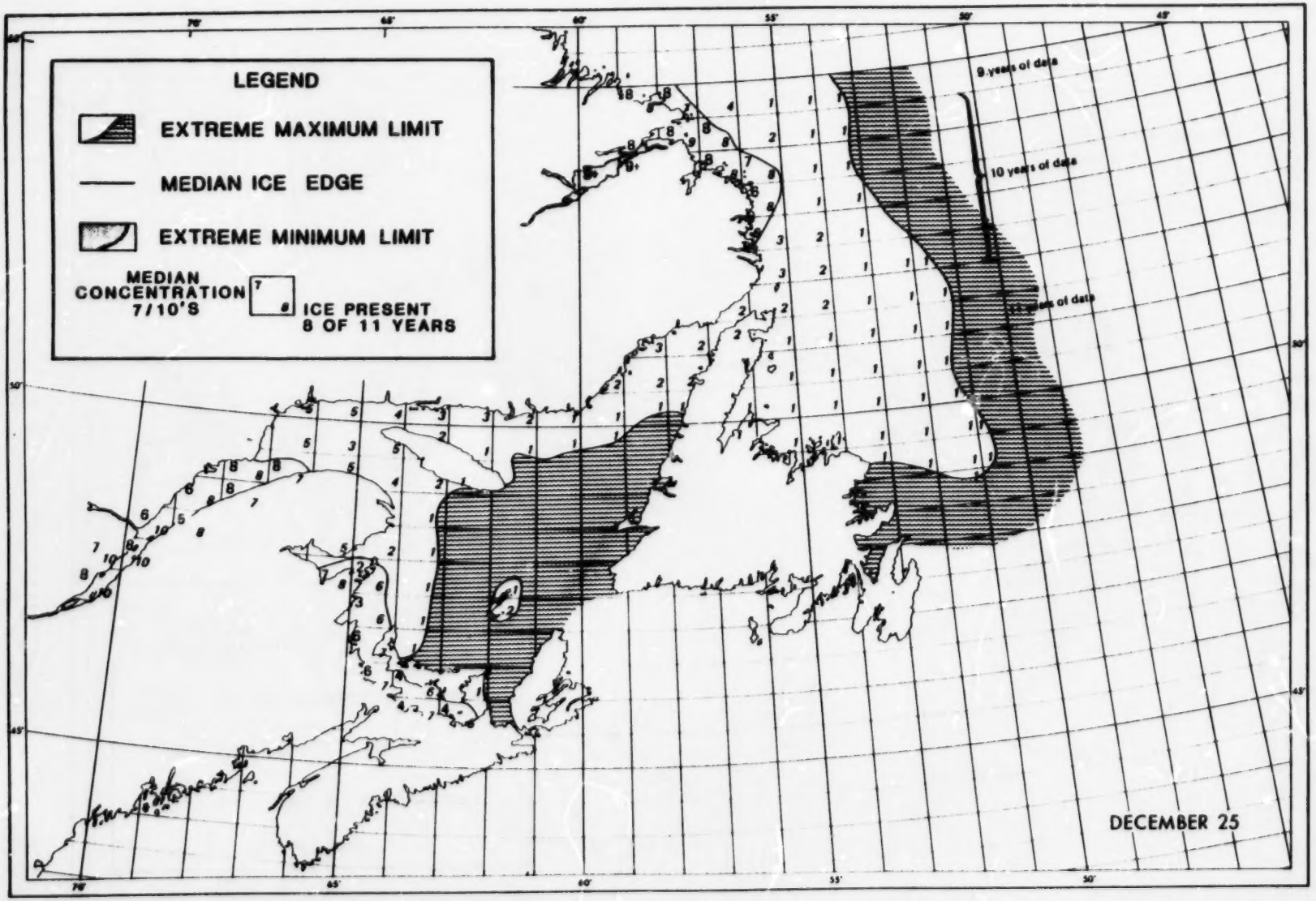
SOUTHERN LABRADOR SHELF AND NE NEWFOUNDLAND SHELF

A.5 MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973

The following series of nineteen bi-weekly charts show the median and extreme ice edge positions for the East Coast waters south of latitude 55 for the eleven year period 1963-1973. They have been extracted from Markham (1980) and in addition to the climatological boundaries show the number of years ice was present and the median concentration of the ice for half degree latitude by one degree longitude grid areas. The legend is complete with the exception of the dashed line which represents the changes in the extreme ice limits that occurred during the 1973 ice season.

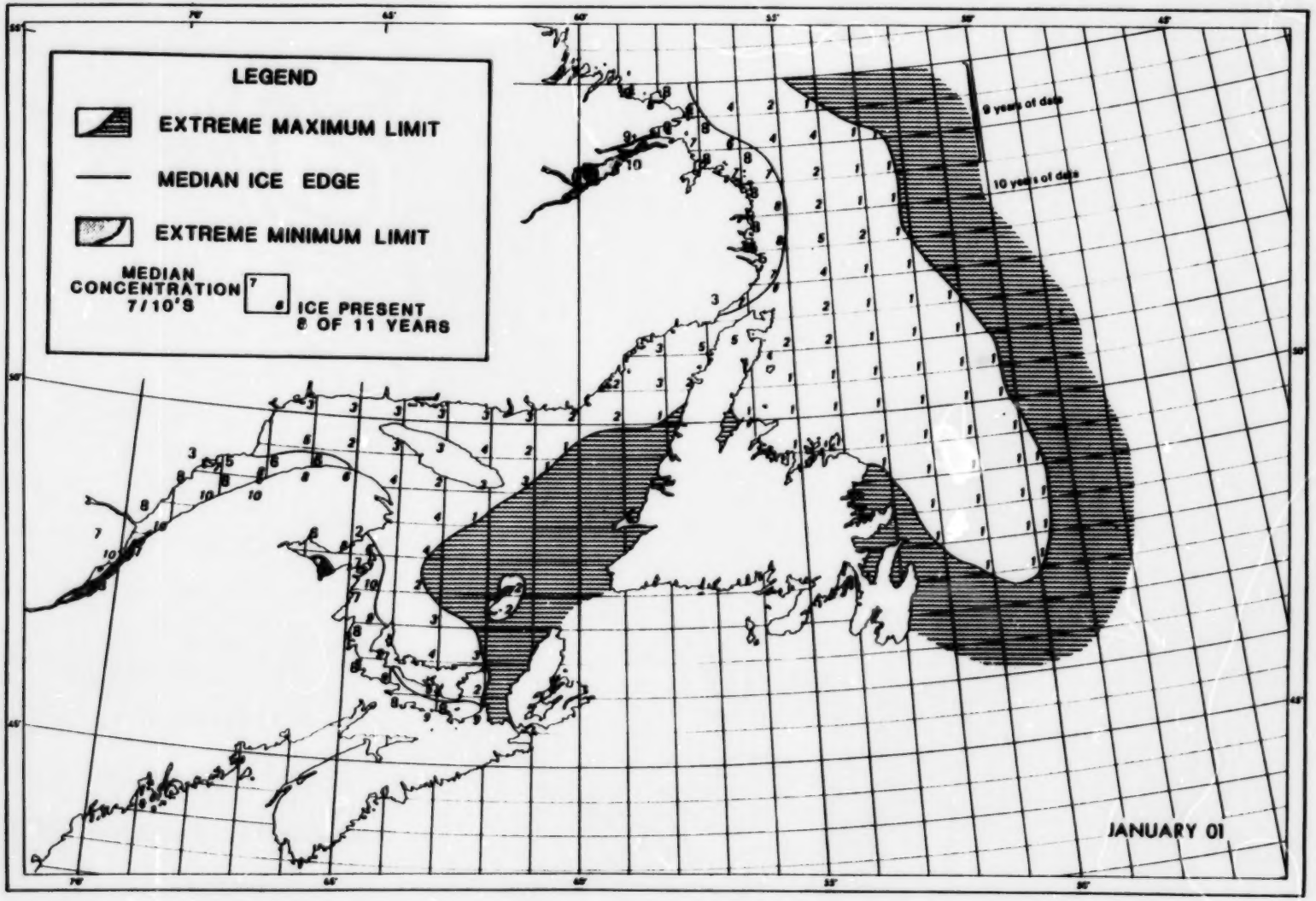


MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973
(FROM MARKHAM, 1980)



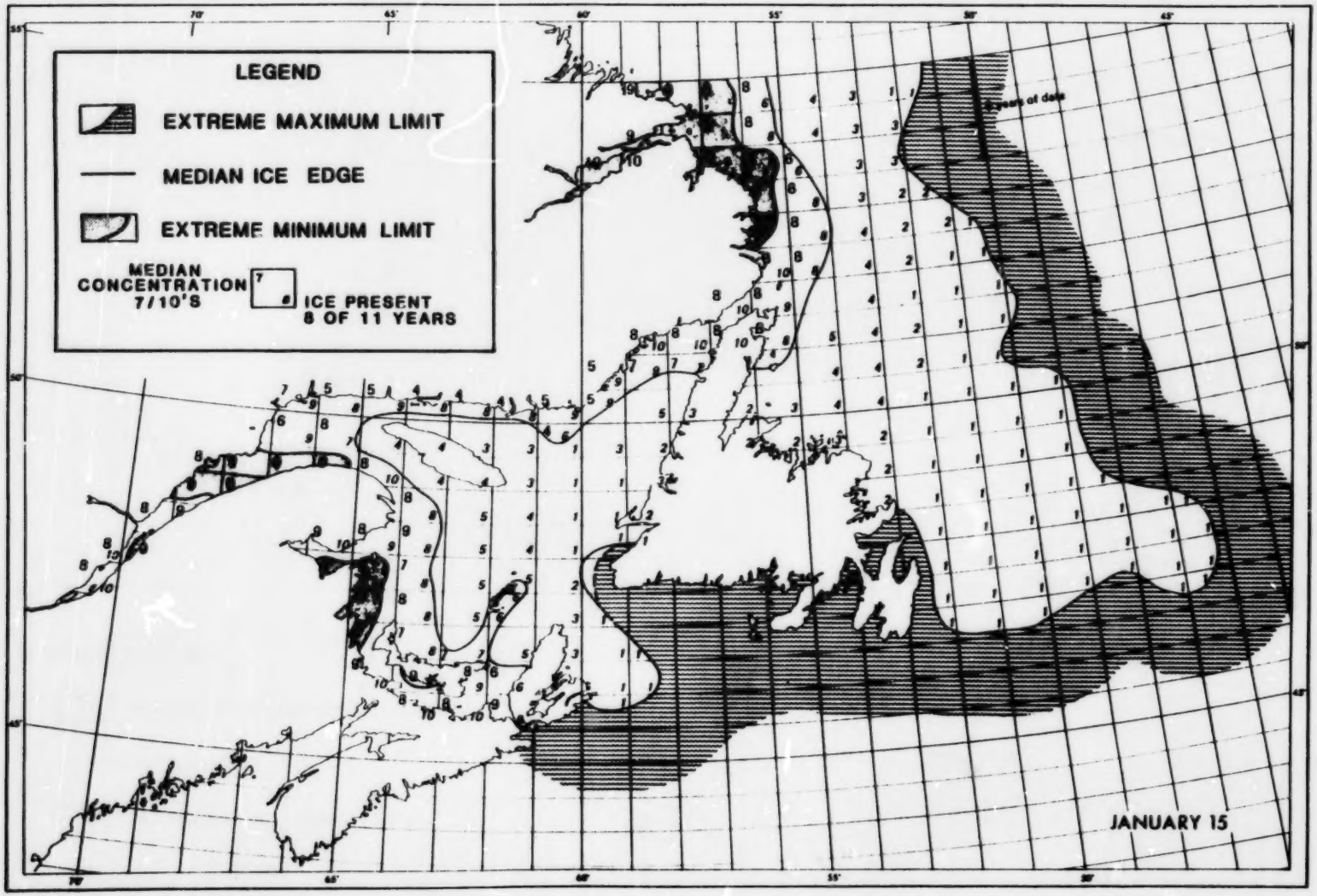
MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973
(FROM MARKHAM, 1980)

NORDCO LIMITED



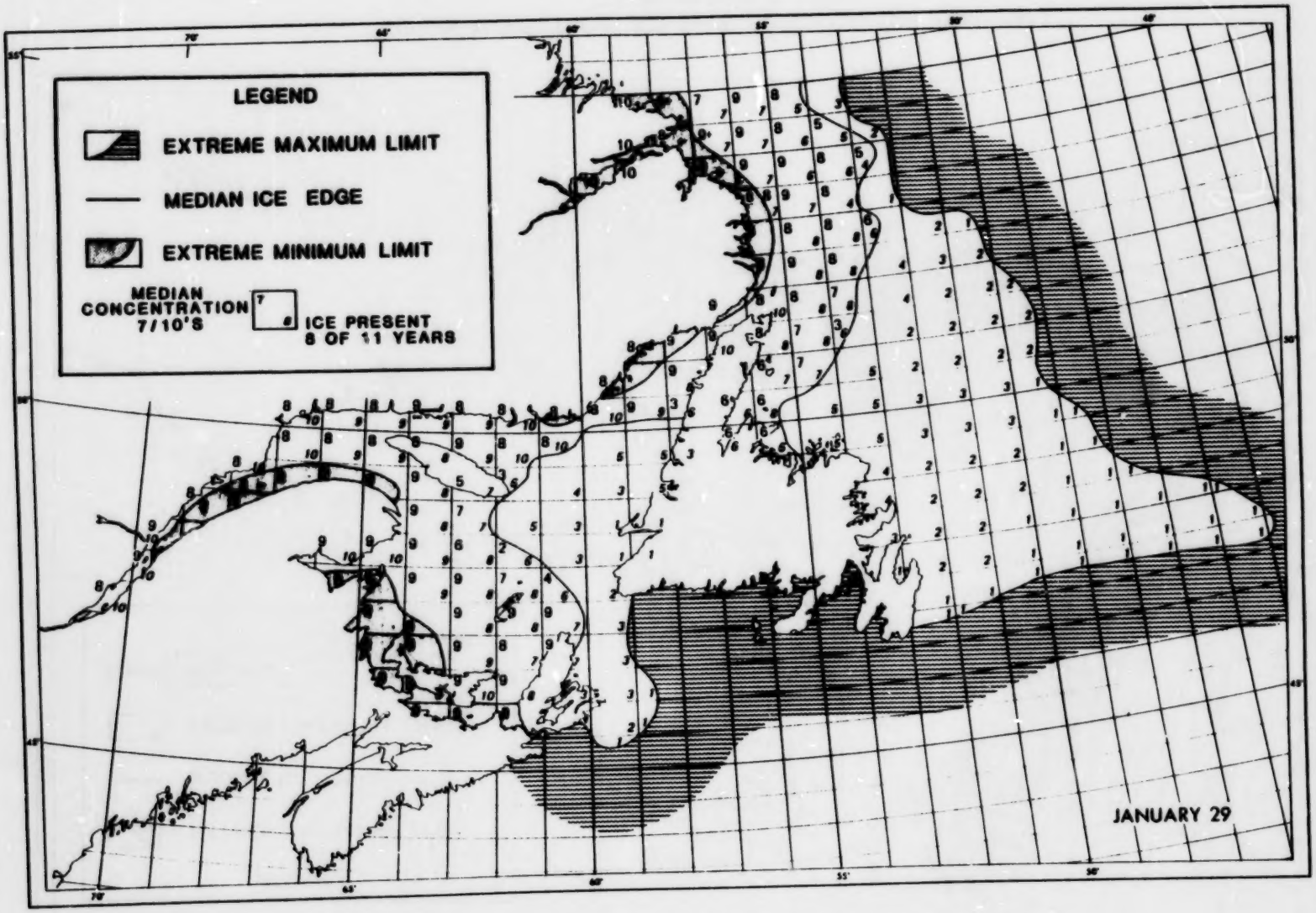
MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973
(FROM MARKHAM, 1980)

NORDCO LIMITED



MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963–1973
(FROM MARKHAM, 1980)

NORDCO LIMITED



MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973
(FROM MARKHAM, 1980)

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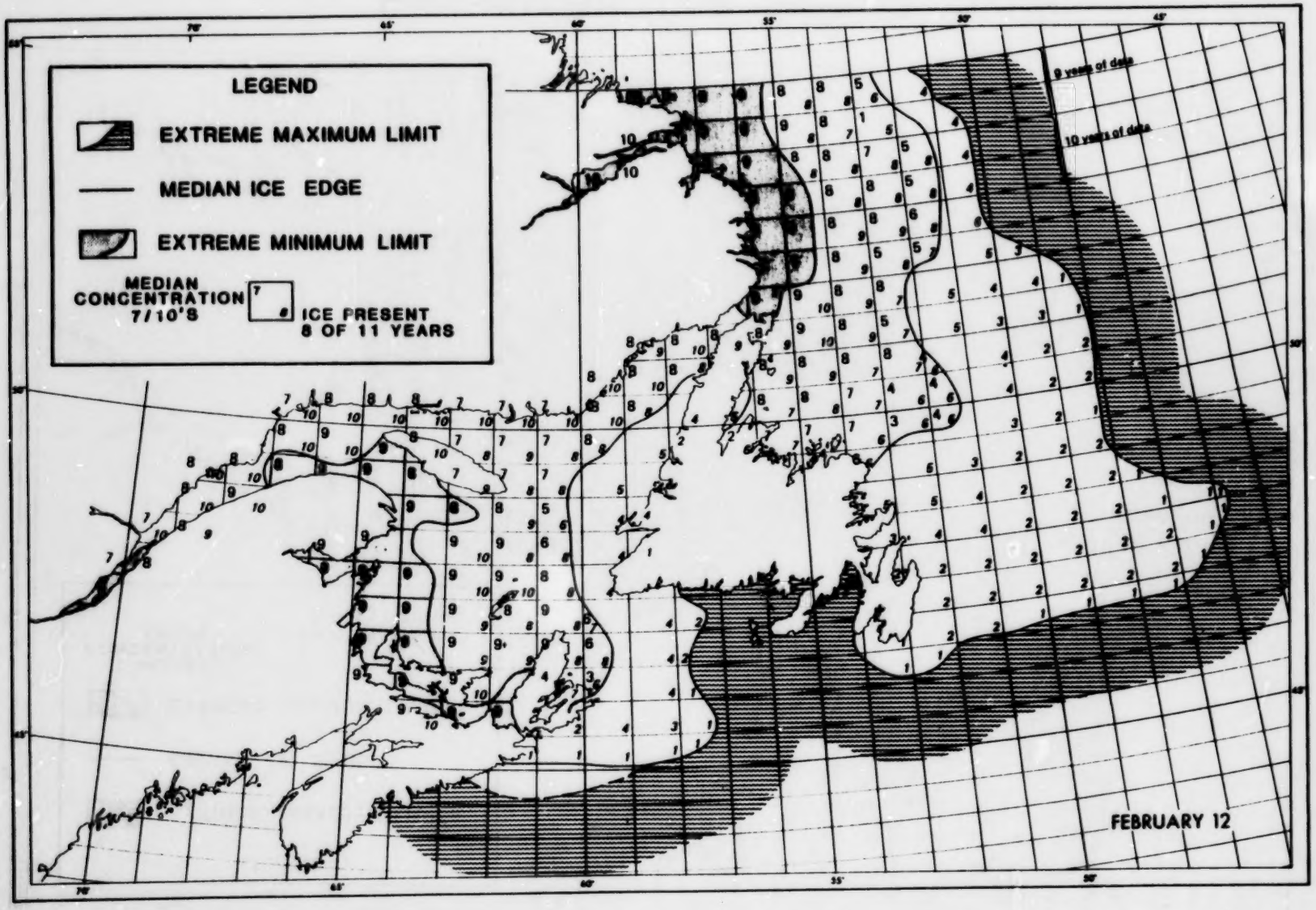

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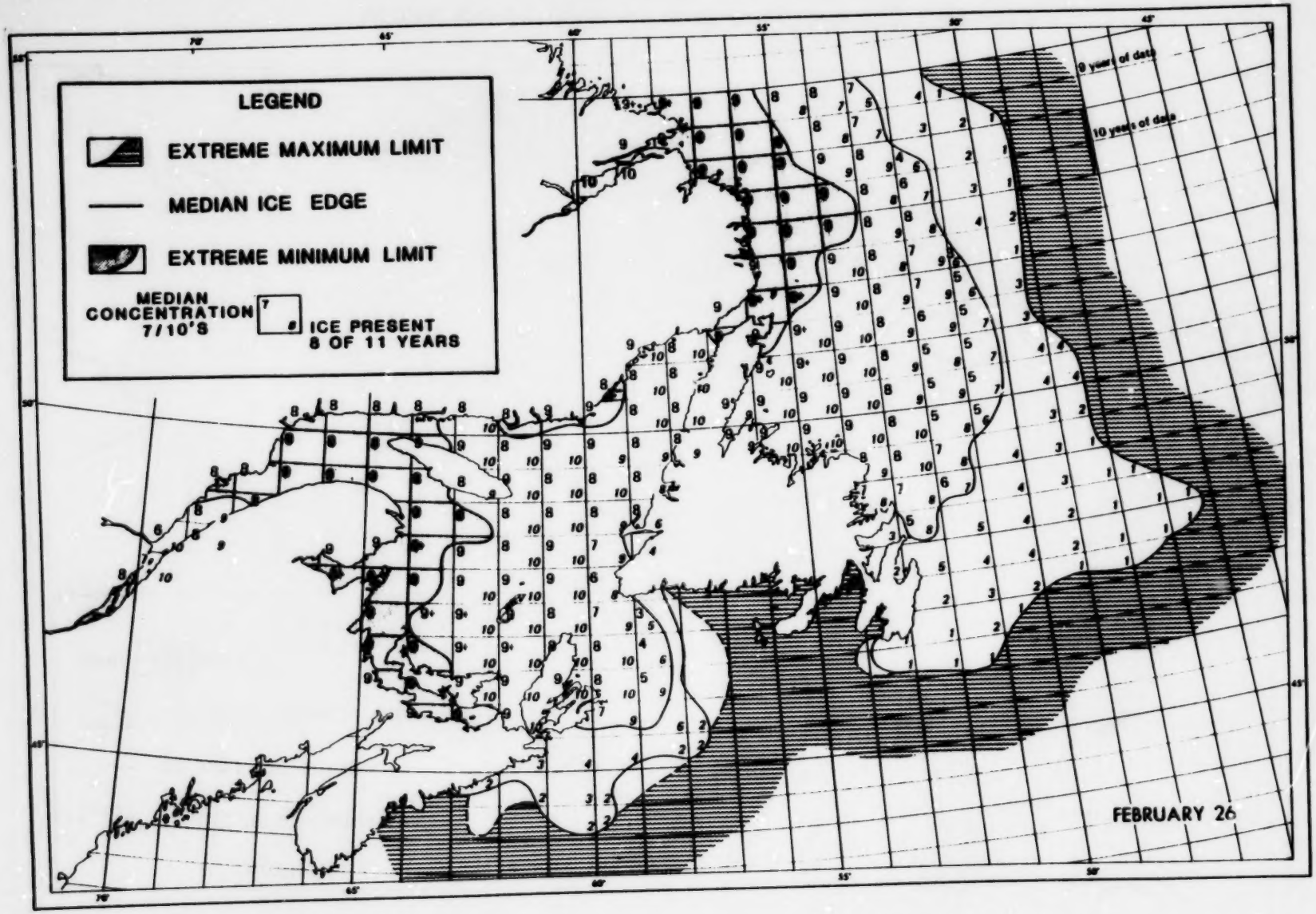

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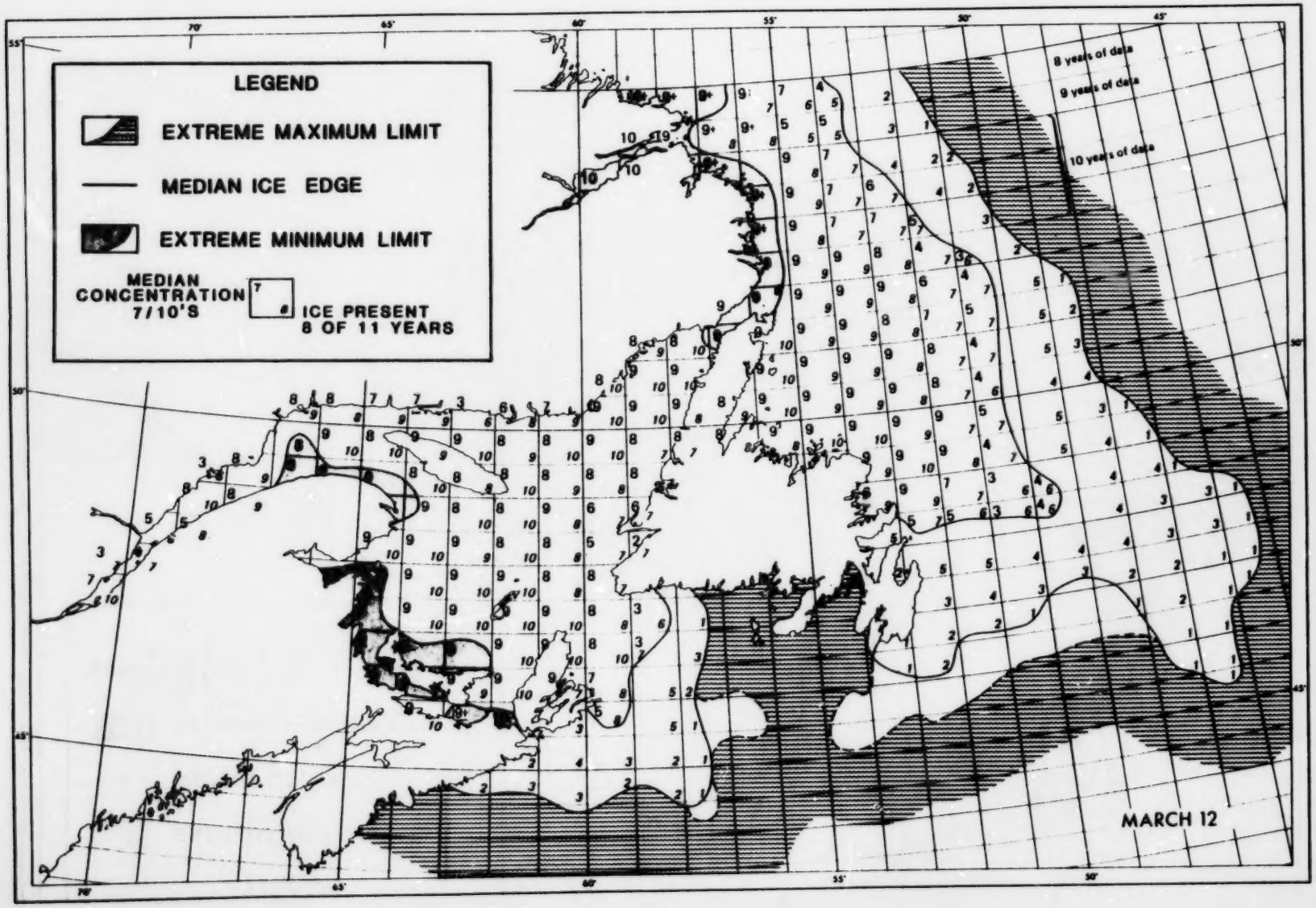

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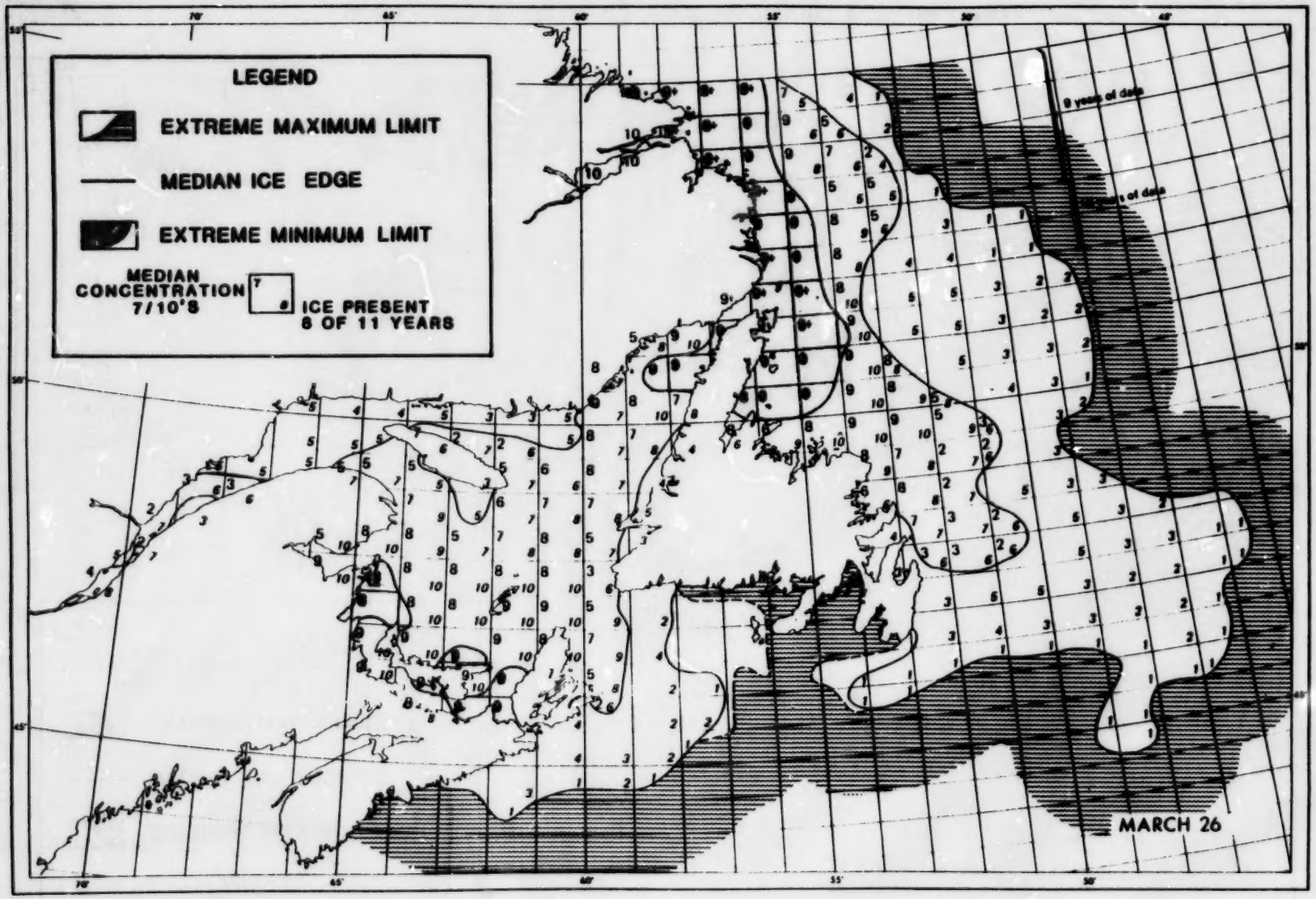

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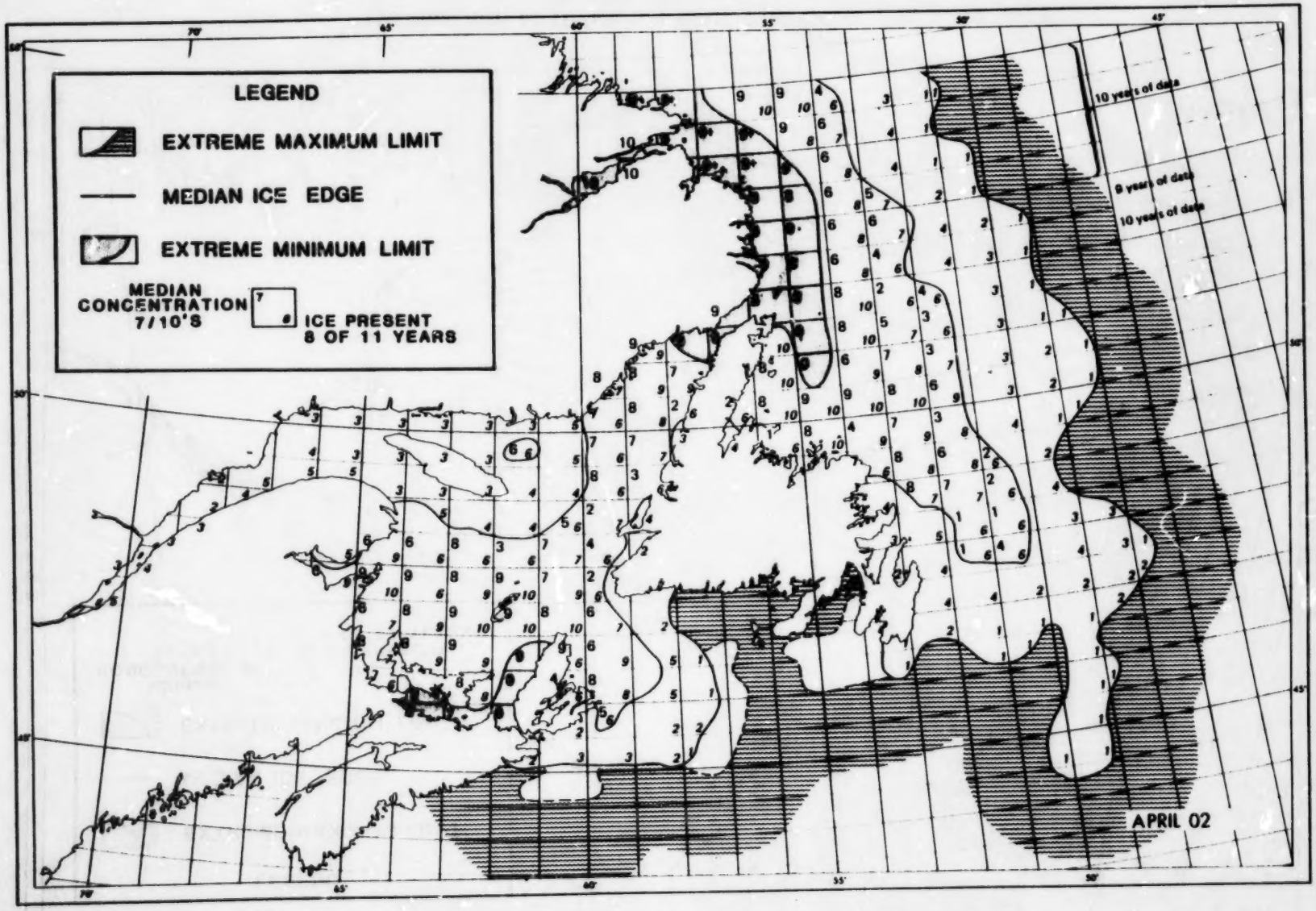
NORDCO LIMITED



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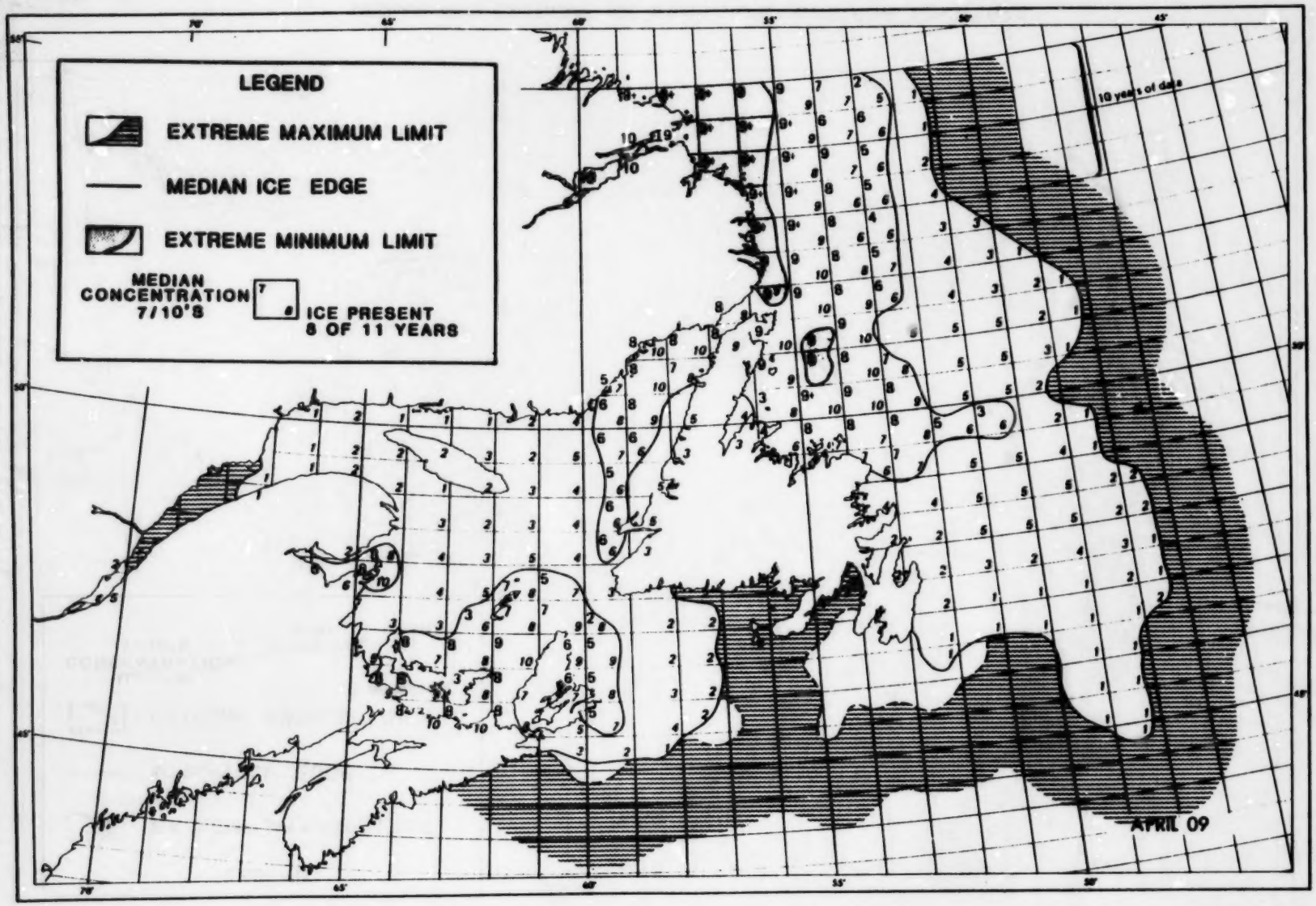

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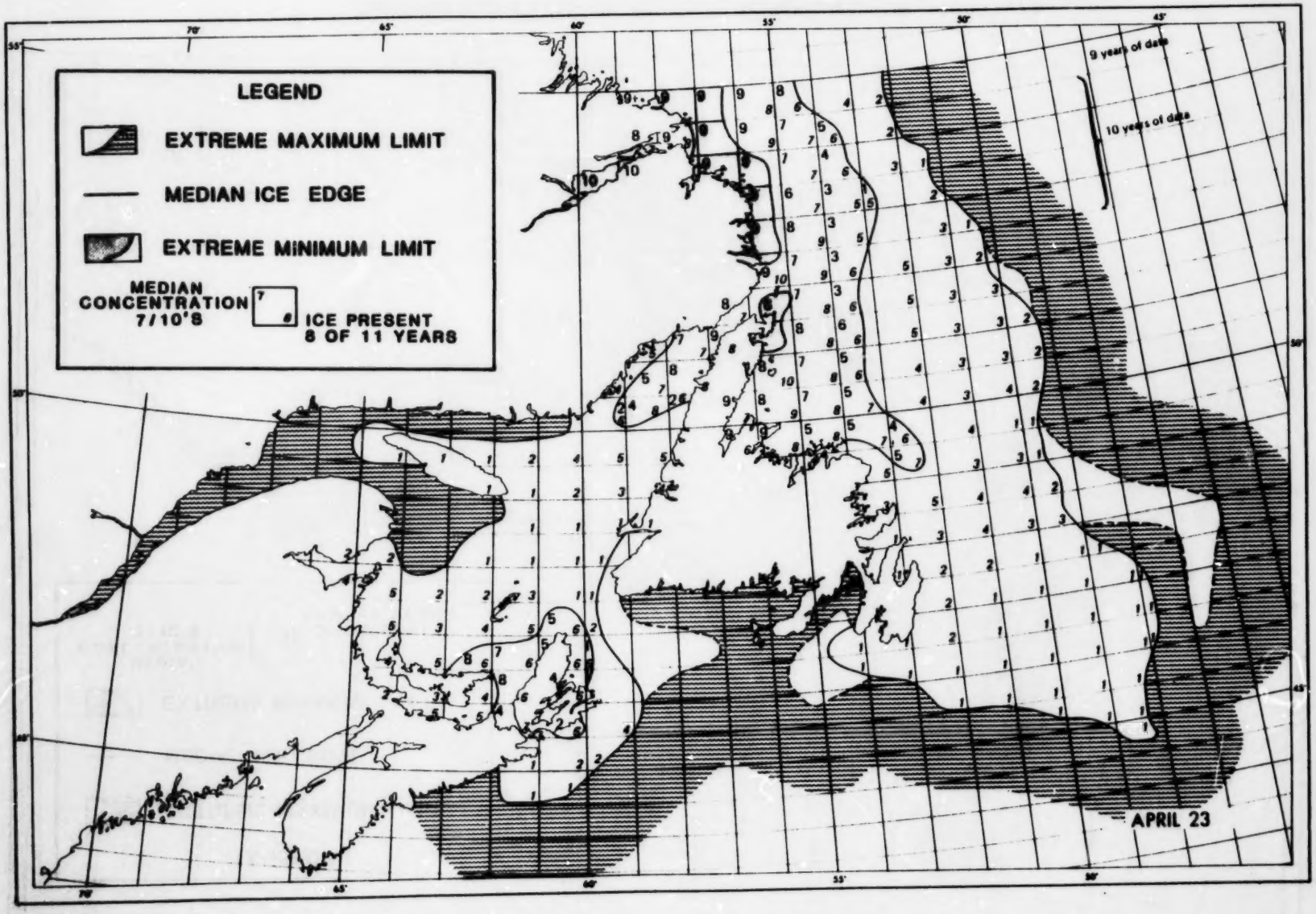
(FROM MARKHAM, 1980)

NORDCO LIMITED



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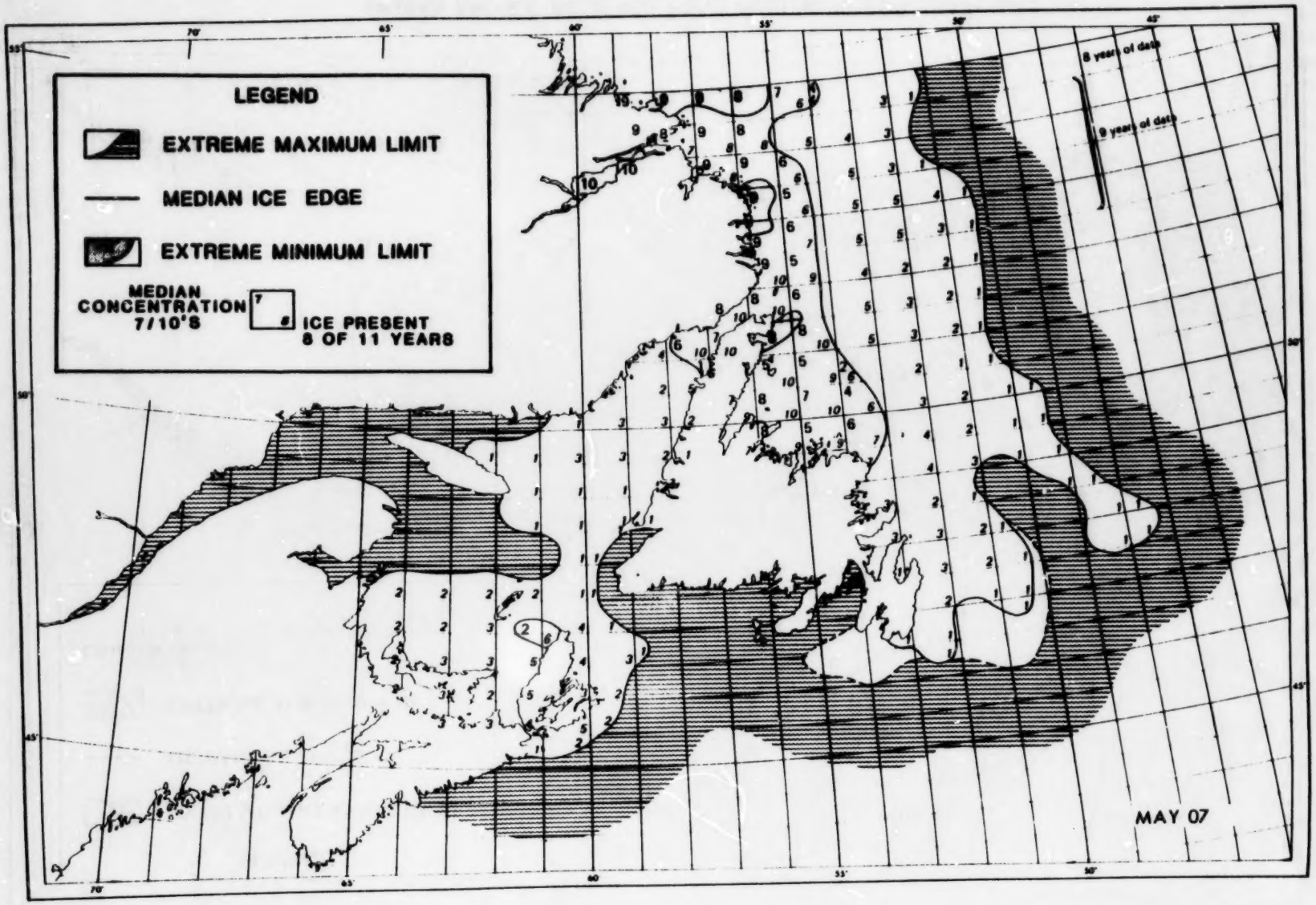

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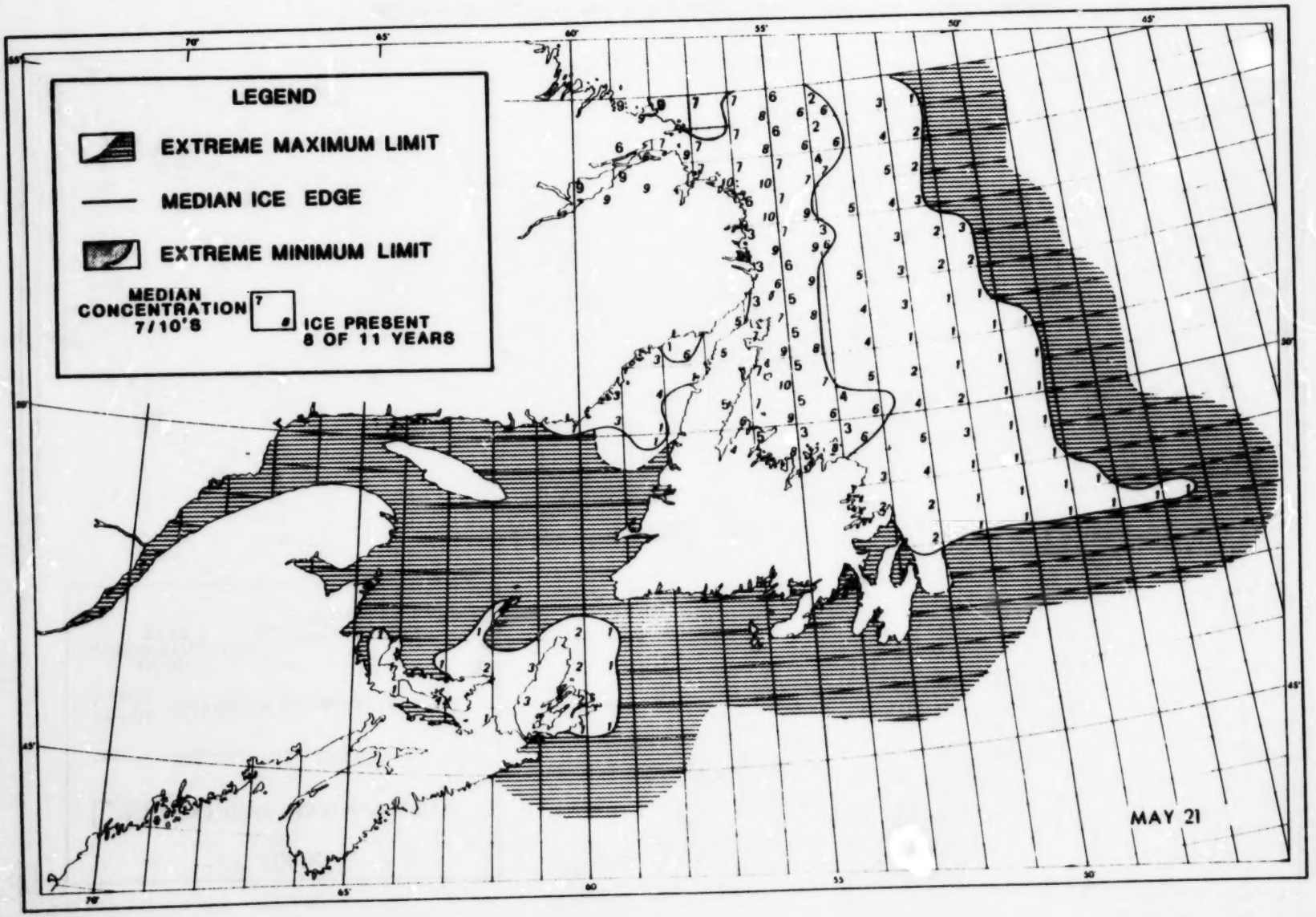

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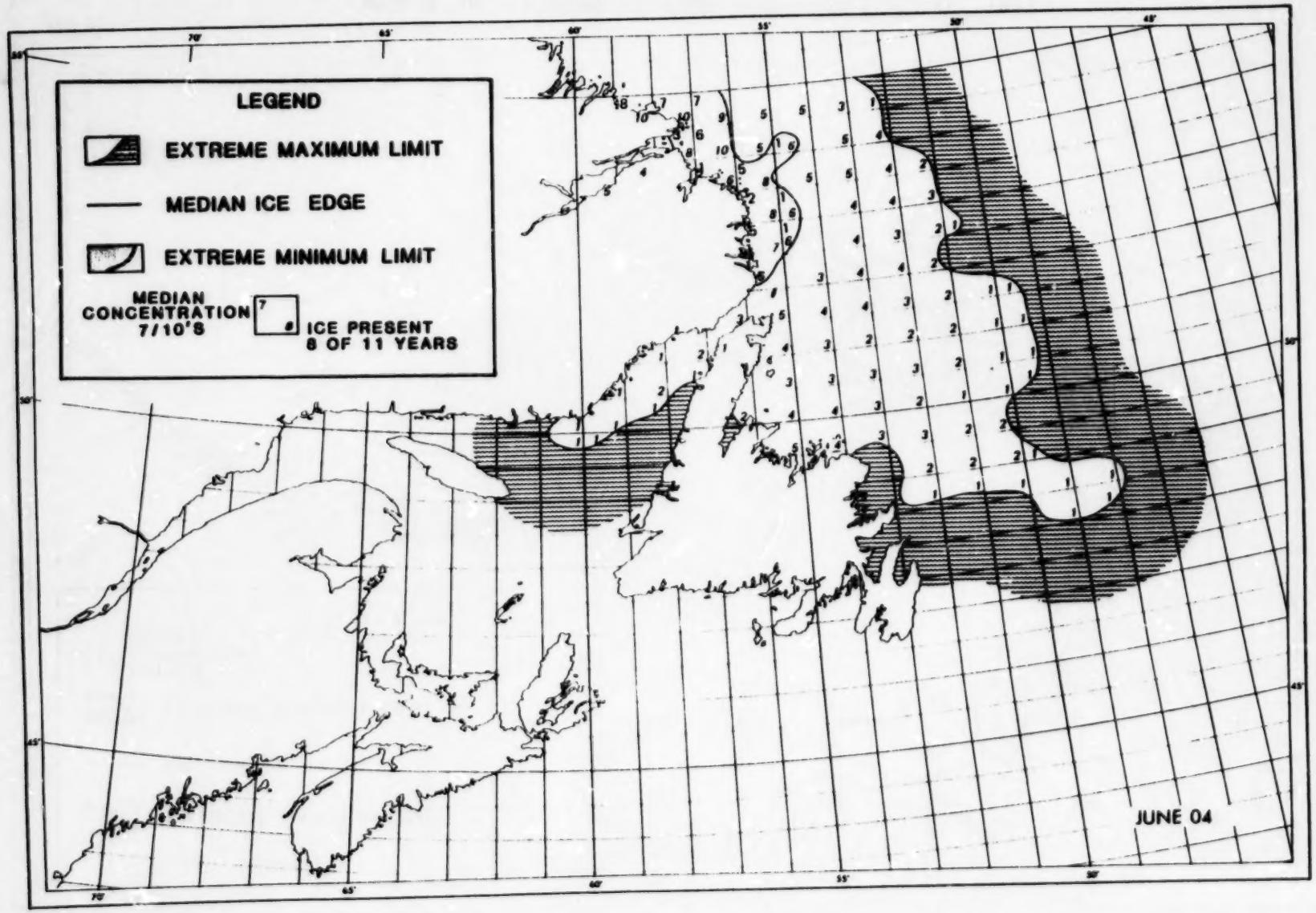

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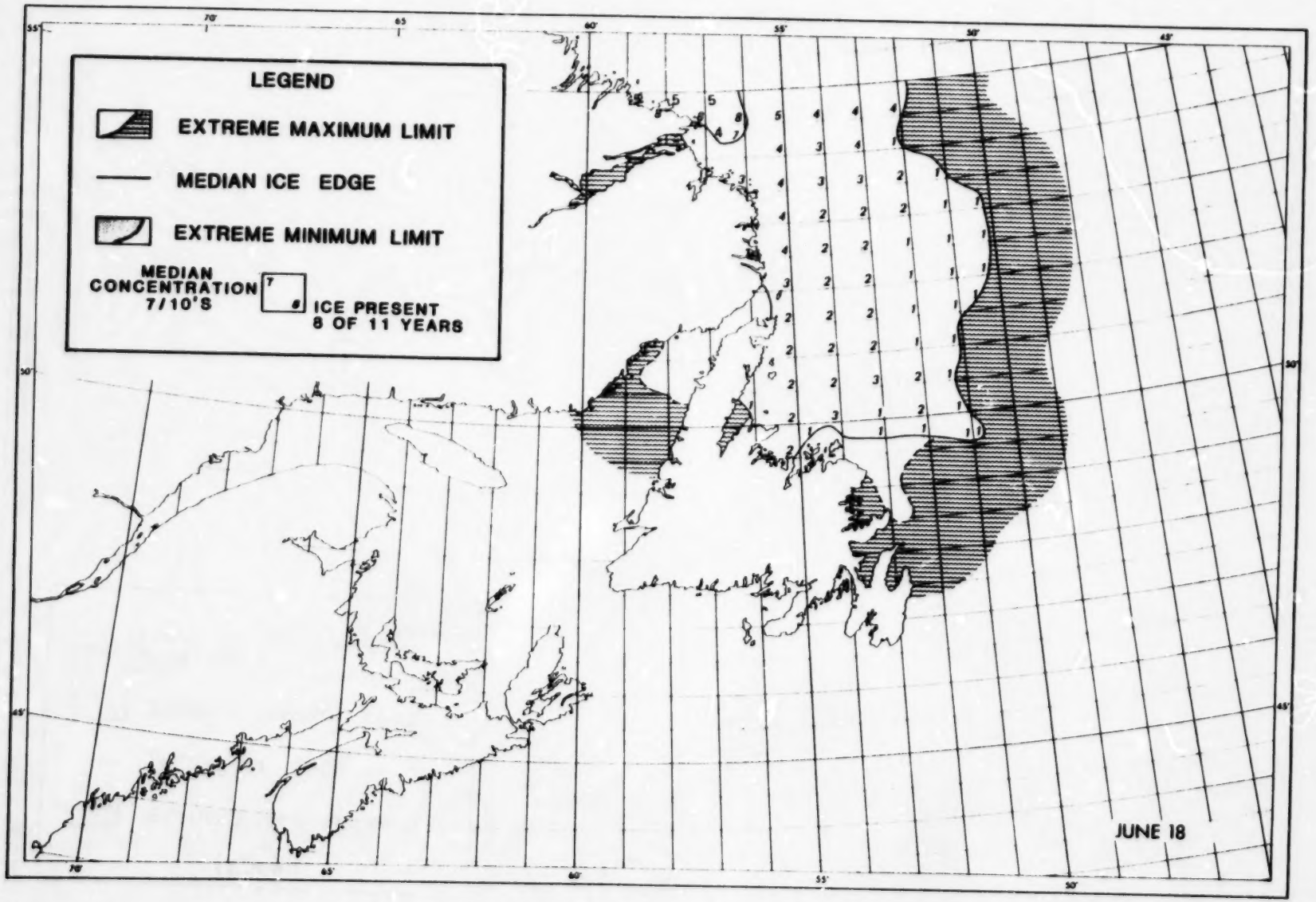

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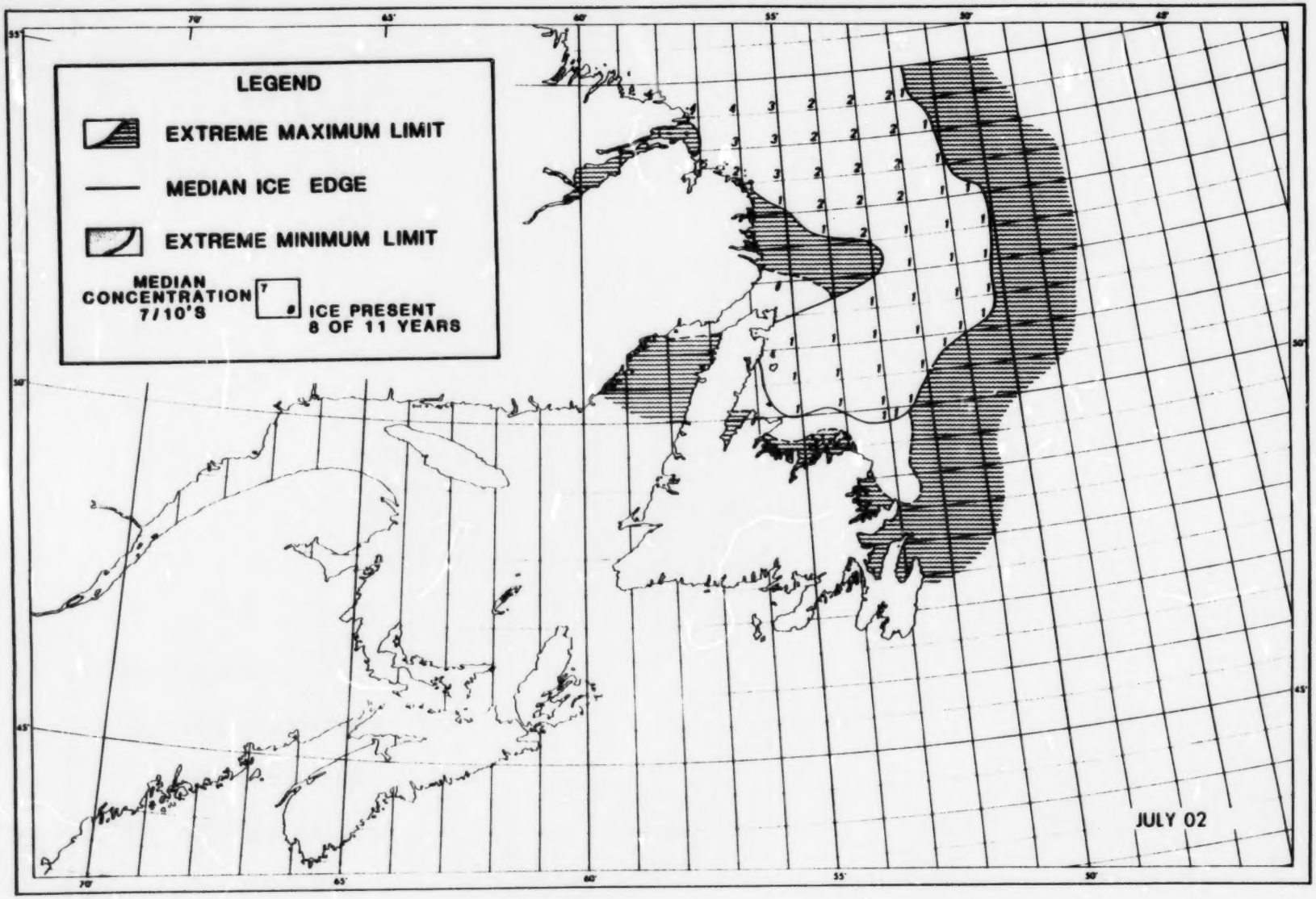

MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973
(FROM MARKHAM, 1980)

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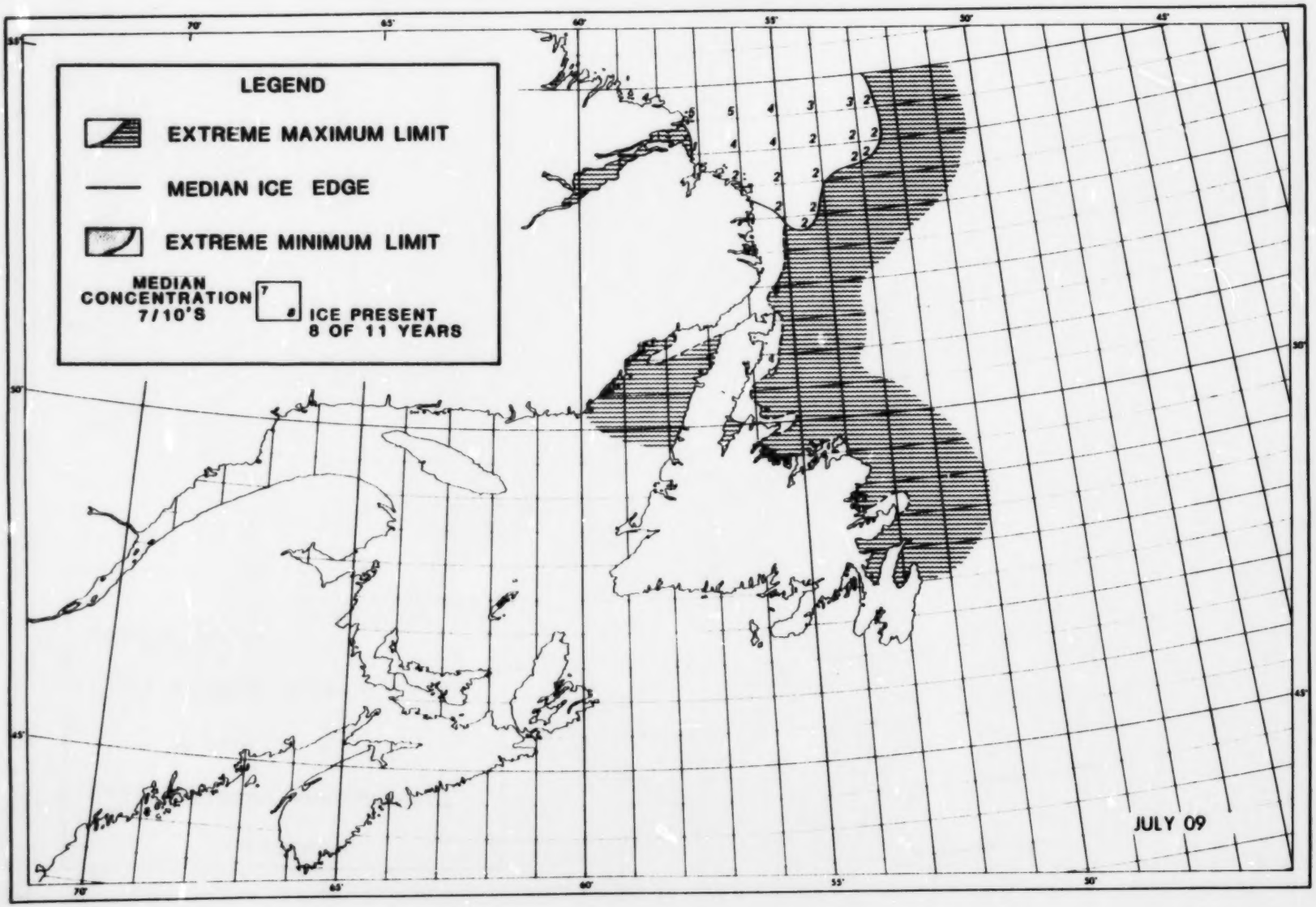

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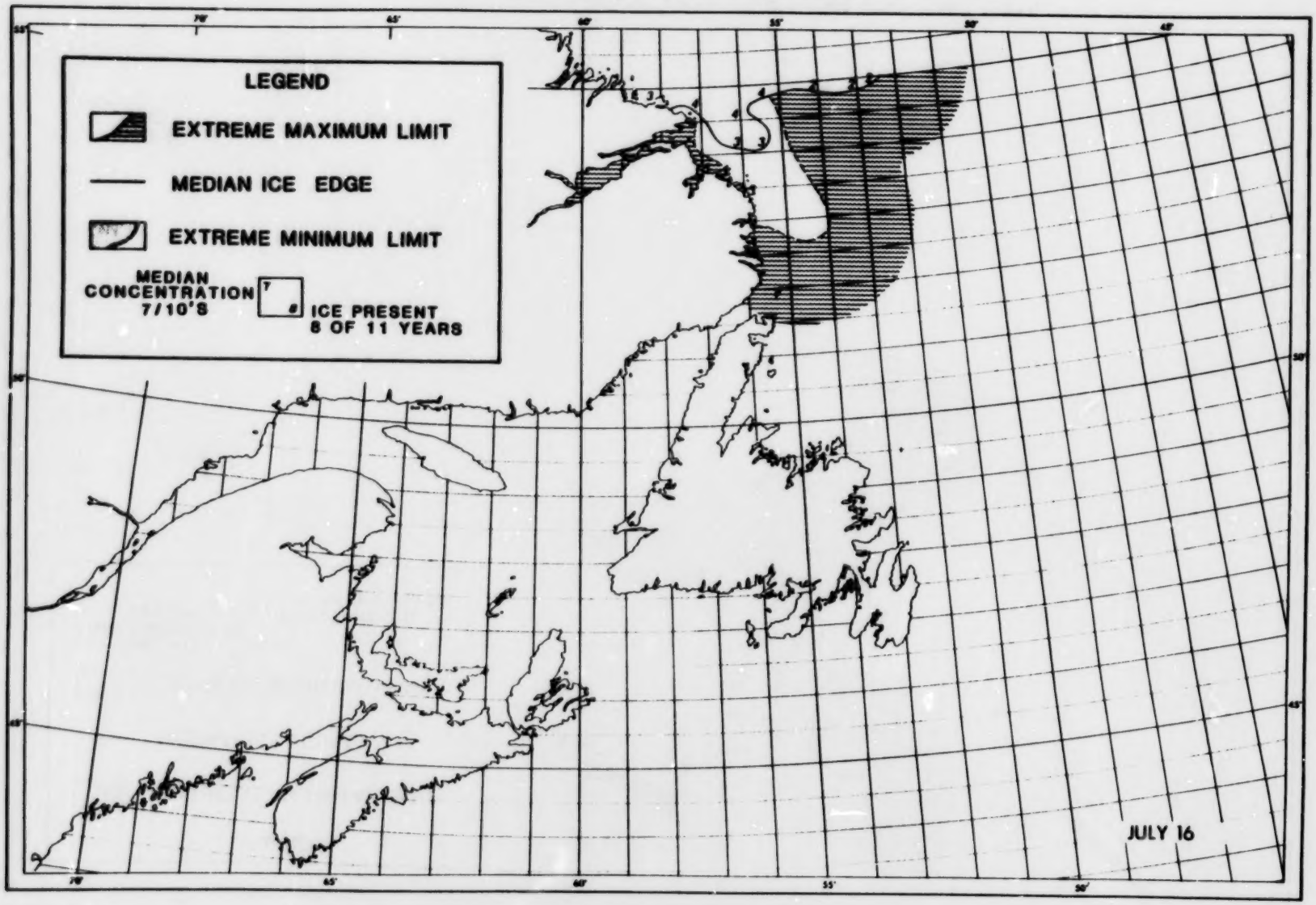


MEDIAN AND EXTREME ICE EDGE POSITIONS FOR 1963-1973
(FROM MARKHAM, 1980)

NON-CONFIDENTIAL

A.6 MEAN ICEBERG POPULATION DENSITIES OFF THE CANADIAN EAST COAST

The following four figures show the average iceberg density distribution along the Labrador Coast for each season of the year based on IIP reconnaissance flights between January 1963 and February 1977 as determined by Gustajtis and Buckley (1977). In this study, the seasons are defined as:

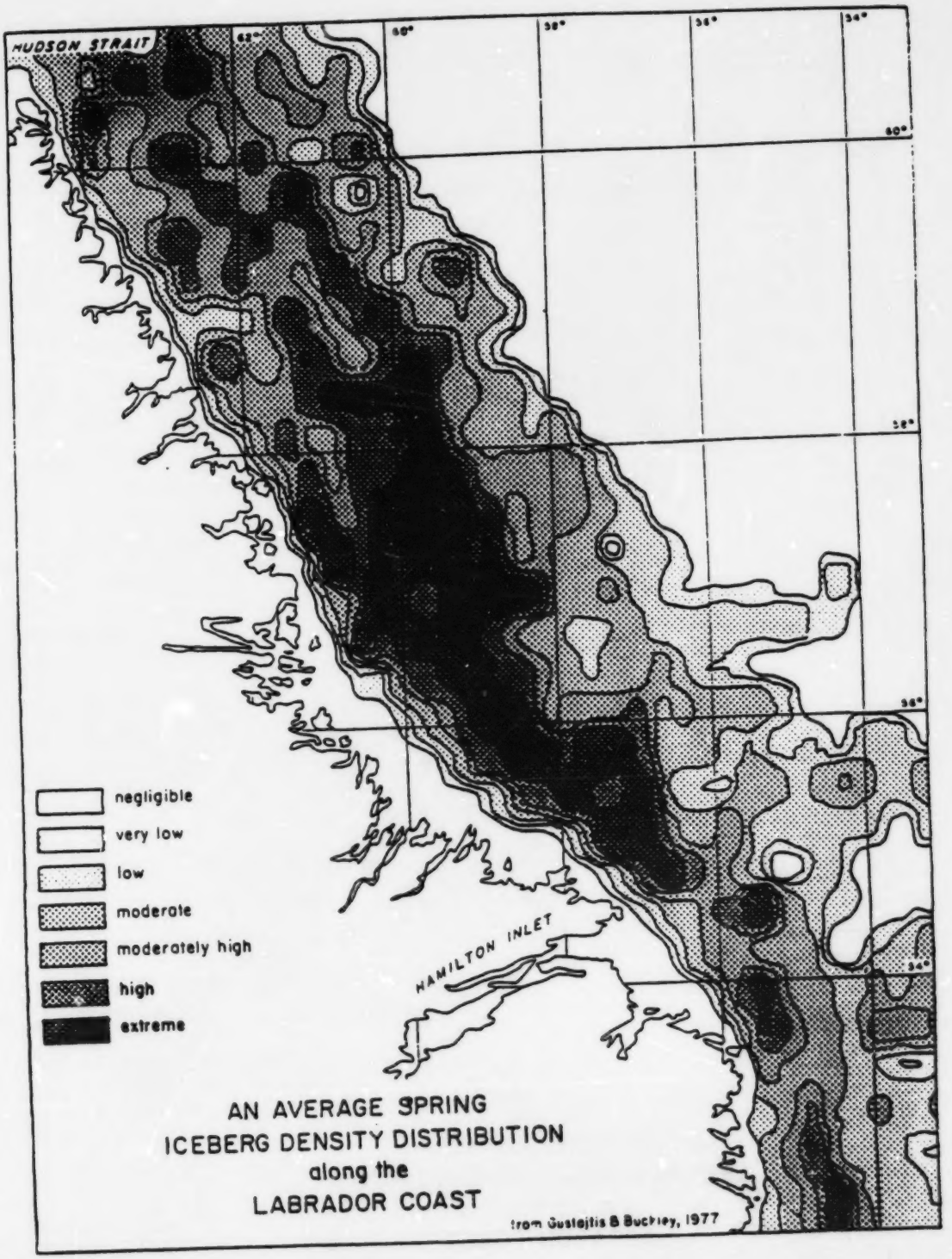
Spring. . . . . .February, March, and April
Summer. . . . . .May, June, July, and August
Fall. . . . . .September and October
Winter. . . . . .November, December, and January

The relative concentrations illustrated by the graduated tone are related to the absolute number of icebergs per 0.25 latitude-longitude grid area according to the following scheme:

Classification	Number of icebergs (N)
Negligible	0 <= N <= 1
Very low	1 <= N <= 2
Low	2 <= N <= 5
Moderate	5 <= N <= 10
Moderately high	10<= N <= 15
High	15<= N <= 20
Extreme	N > 20

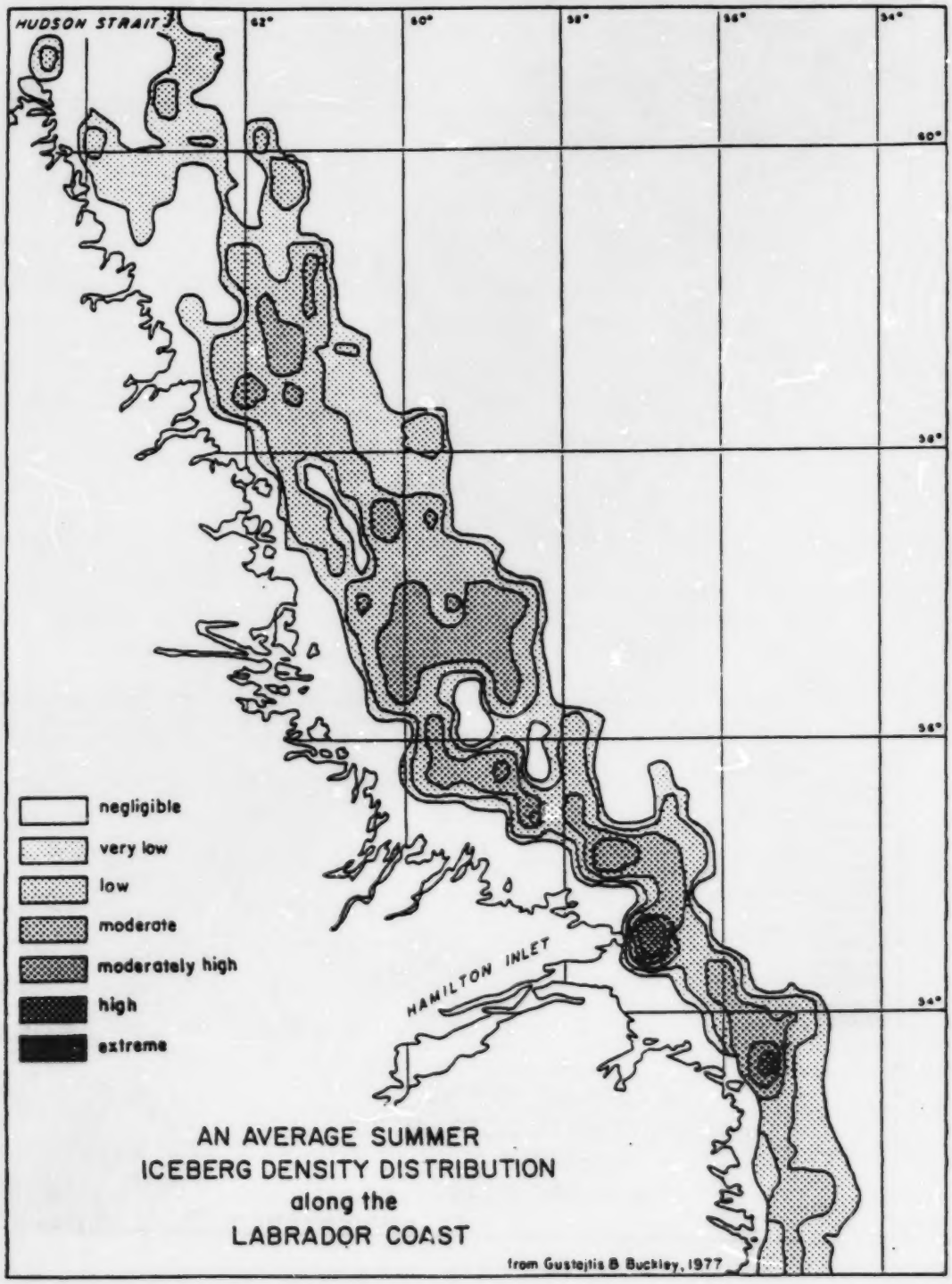
Following the figures showing iceberg density distribution for the Labrador Coast, two maps are presented which show average iceberg densities in Newfoundland waters during the spring and summer seasons as determined from IIP surveys between 1967 to 1977. The figures show the average number of icebergs that were found in each latitude-longitude grid area in each of these seasons. Iceberg

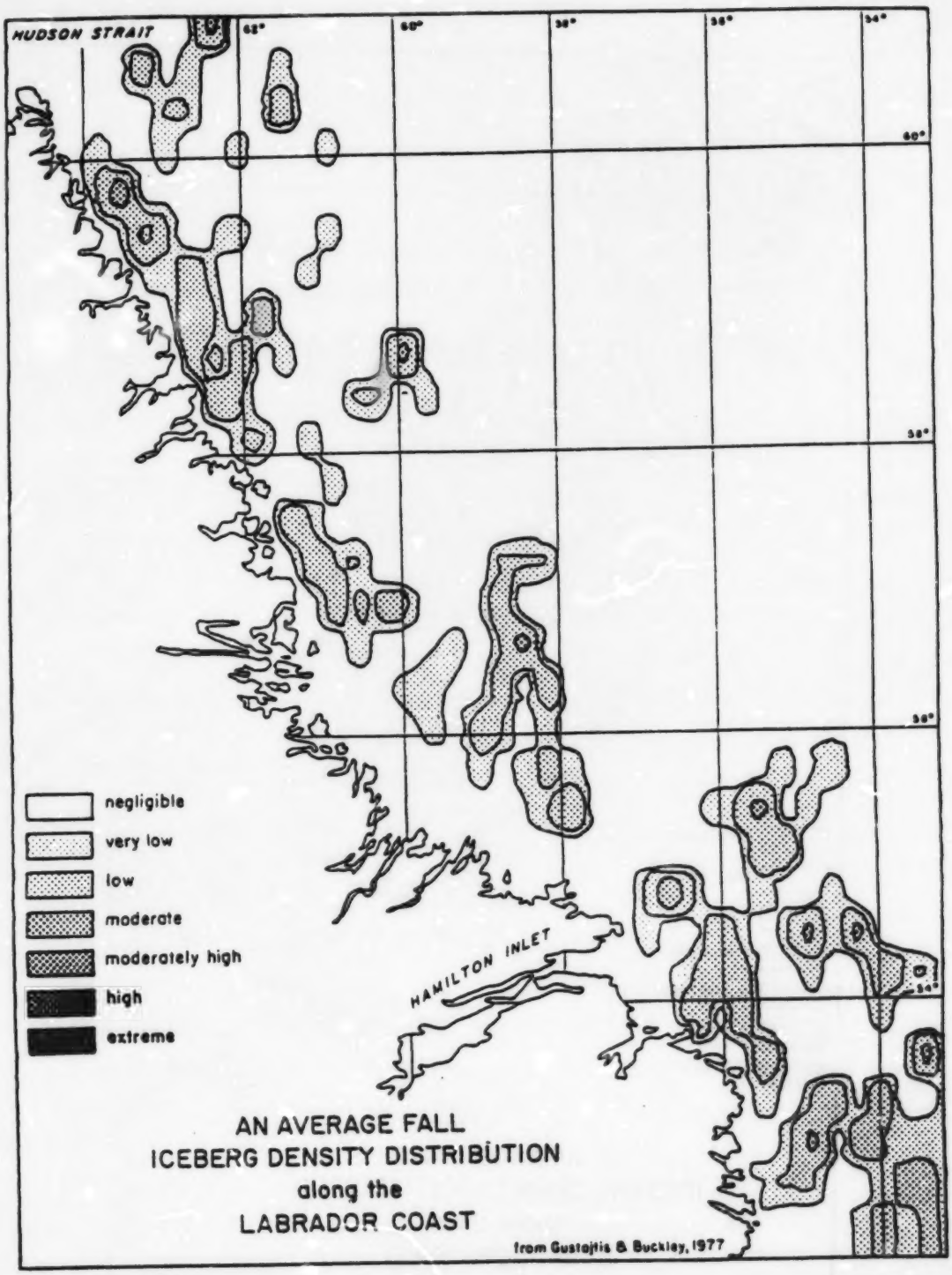
populations are near zero in Newfoundland waters during the late summer, autumn, and early winter months.

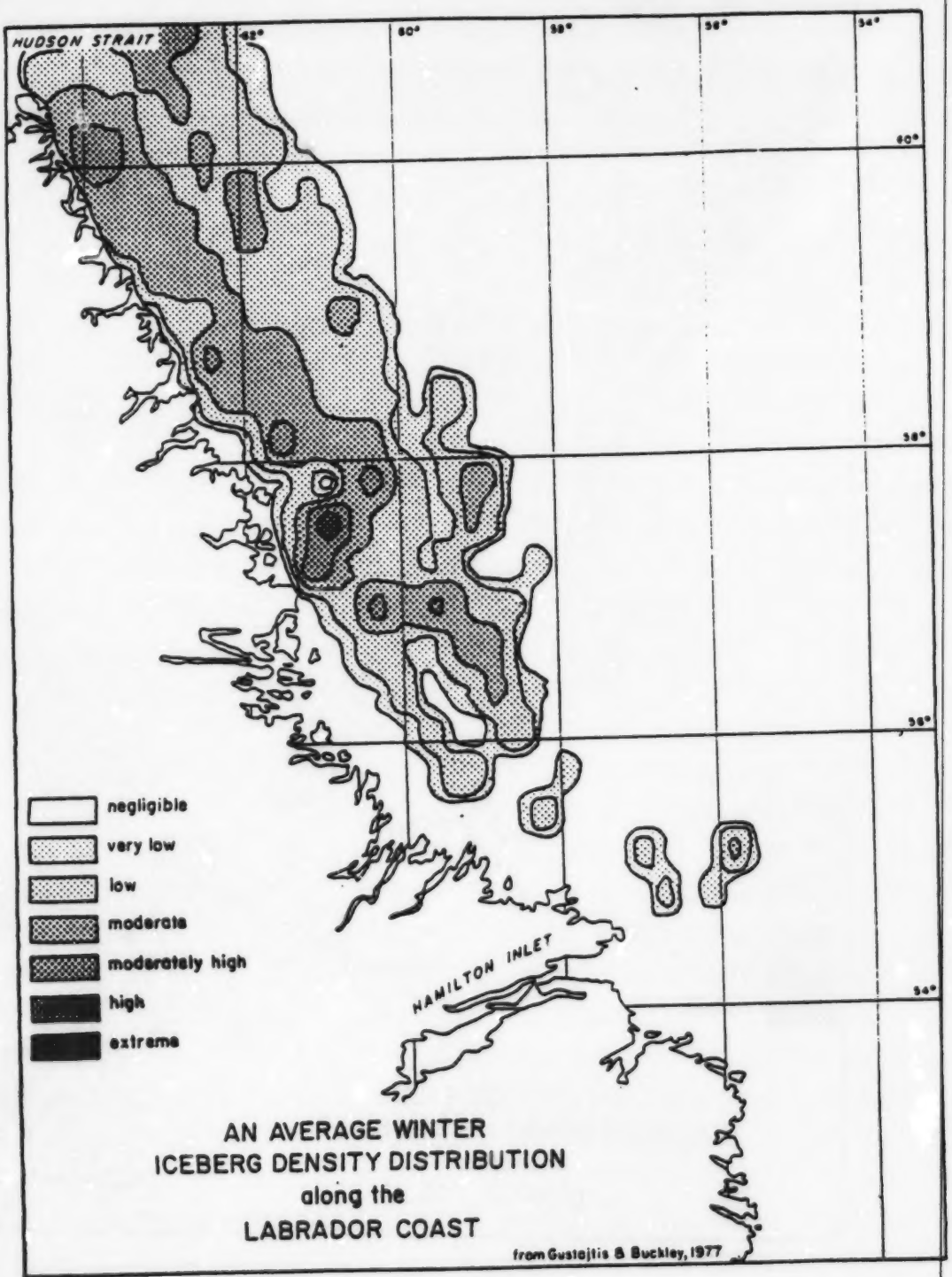


AN AVERAGE SPRING
ICEBERG DENSITY DISTRIBUTION
along the
LABRADOR COAST

from Gustajtis & Buckley, 1977

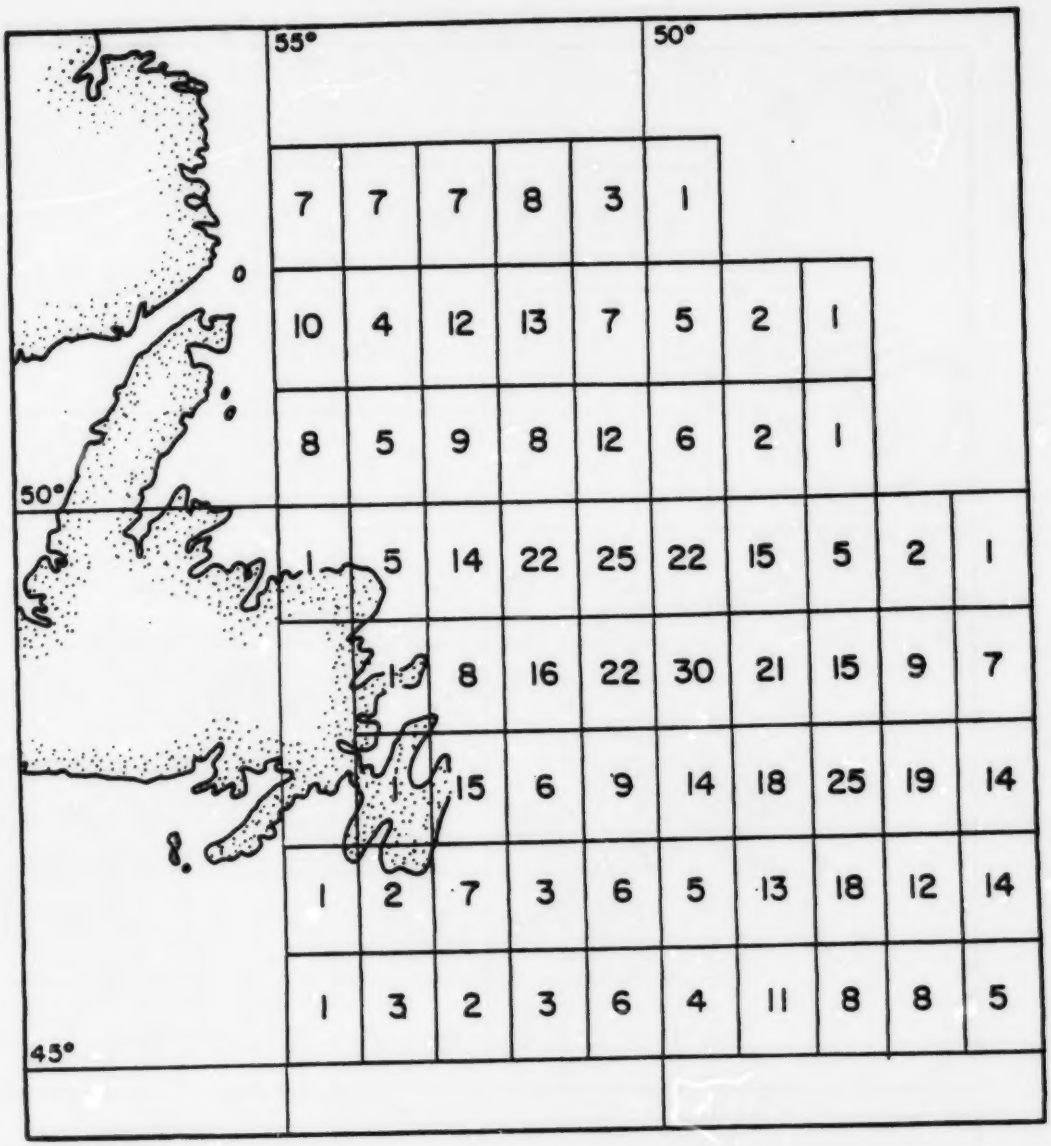

HUDSON STRAIT
62°
60°
58°
56°
54°
60°
58°
56°
54°
negligible
very low
low
moderate
moderately high
high
extreme
HAMILTON INLET
AN AVERAGE SUMMER
ICEBERG DENSITY DISTRIBUTION
along the
LABRADOR COAST
from Gustajtis & Buckley, 1977


HUDSON STRAIT
62°
60°
58°
56°
54°
60°
58°
56°
54°
negligible
very low
low
moderate
moderately high
high
extreme
HAMILTON INLET
AN AVERAGE FALL
ICEBERG DENSITY DISTRIBUTION
along the
LABRADOR COAST
from Gustajtis & Buckley, 1977

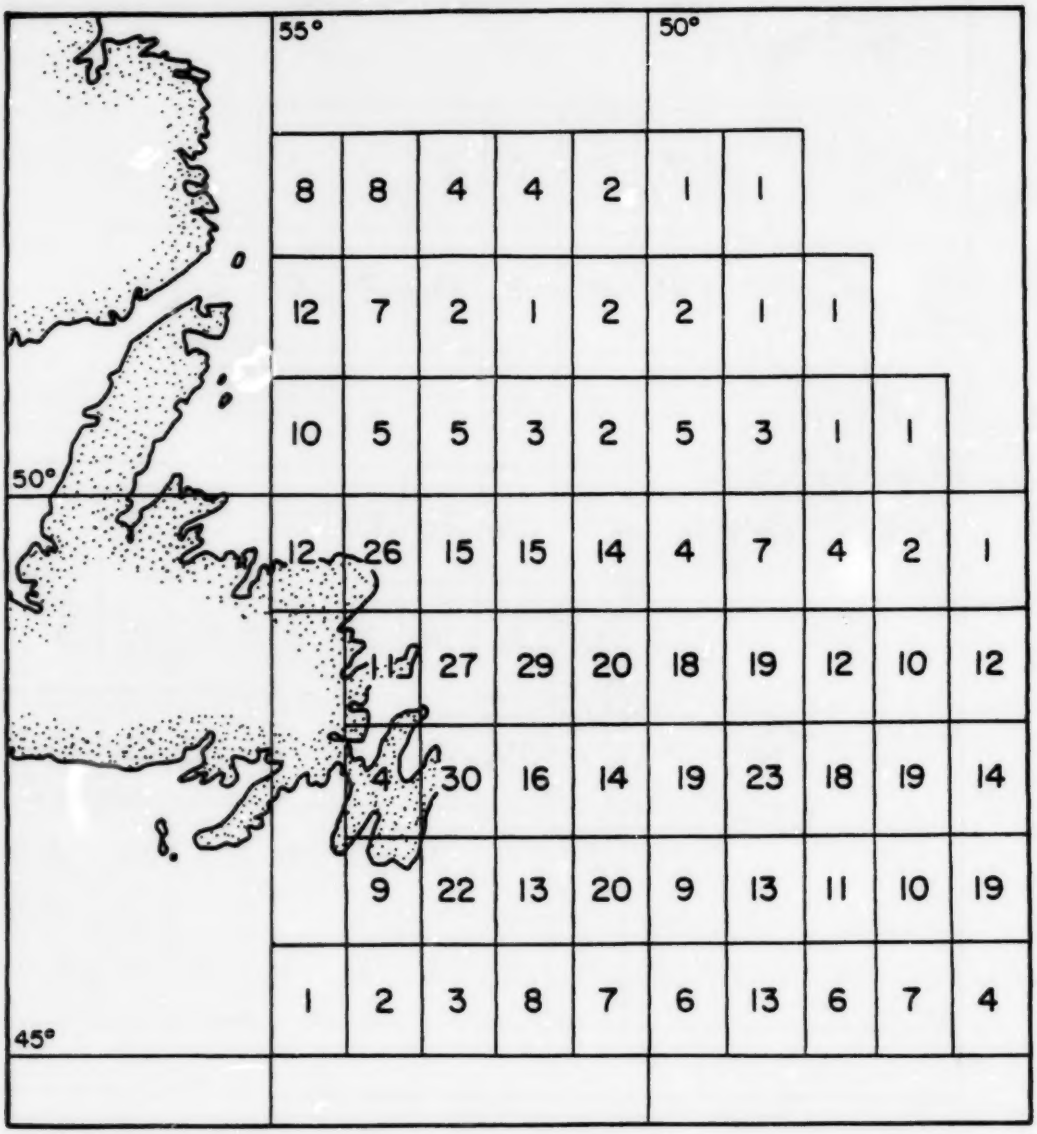


AN AVERAGE WINTER
ICEBERG DENSITY DISTRIBUTION
along the
LABRADOR COAST

from Gustajtis & Buckley, 1977



AN AVERAGE SPRING ICEBERG DENSITY DISTRIBUTION OFF THE NEWFOUNDLAND COAST DURING 1967-76 BY I I P



AN AVERAGE SUMMER ICEBERG DENSITY DISTRIBUTION OFF THE NEWFOUNDLAND COAST DURING 1967-76 BY I I P

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APPENDIX B

DETECTABILITY OF SURFACE TARGETS BY ACOUSTIC METHODS

Prepared By:
Dr. A. Zielinski
Faculty of Engineering
Memorial University of Newfoundland

1. Introduction

The general scenario shown in Figure 1 is considered to evaluate limits of target detectibility using acoustic methods.

A target can be a passive object floating on the surface or suspended from the surface to a certain depth. A sonar system with a narrow beam transmits a short acoustic pulse toward the target and detection is based on the received echo. Aternatively, a target can be equipped with a transponder which retransmits an acoustic pulse upon receiving an interrogating pulse. In order to avoid surface reverberation, it is desirable that the retransmitted pulse has a different frequency from that of the interrogating pulse. In a simpler detection scenario a non-transponding pinger is installed on a target and a passive listening sonar is used to detect its presence.

2. Passive Surface Target

The maximum range of the sonar system for surface target detection is primarily limited by the surface reverberation. The echo-to-reverberation ratio is given by (Burdic, 1984):

$$\Delta_s = EL - RL_s = TS - S_s - \frac{1}{2} TL - 10 \log \frac{c\tau\theta}{2} \qquad (1)$$

where,

EL = echo level,

RL_s = surface reverberation level,

TS = target strength,

S_s = surface scattering coefficient,

TL = 20 log r - one way transmission loss,

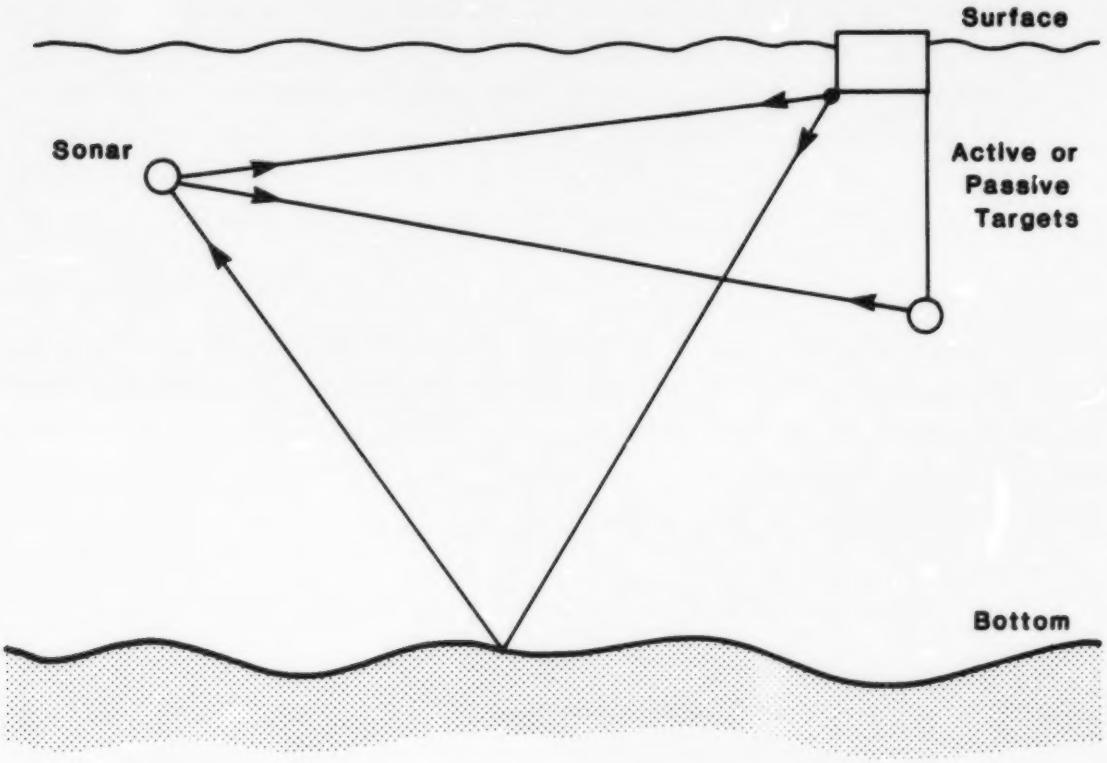

Figure 1. Target Detection By Acoustic Methods

r = range,

c = sound velocity,

τ = pulse duration, and

θ = effective two-way azimuth beamwith (in radians).

The value of S_s increases with frequency, grazing angle and surface roughness. Because of the grazing angle dependence it is possible that, under certain conditions, a close target may not be detected. Typically, S_s is less than - 25 decibels (dB) for f = 60 kHz, a wind speed 17.5 knots and a grazing angle less than 50° (Urick, 1975). For calculation purposes, a spherical target with a radius, a, is considered. For such a target:

$$TS = 20 \log (a/2). \tag{2}$$

Assuming that the required echo-to-reverberation ratio, Δ_s, is 10 dB, τ is 1 ms, S_s is -25 dB, and θ is 10°. Equation (1) becomes:

$$r = 60\, a^2. \tag{3}$$

Equation (3) indicates a very limited range for this detection method for small objects such as survival suits.

3. Passive suspended target

The maximum range of a suspended target detection system is limited by volume reverberation or ambient noise. The echo-to-reverberation ratio is given by (Burdic, 1984):

$$\Delta_v = TS - S_v - TL - 10 \log \frac{c\tau\Omega}{2} \tag{4}$$

where,

S_v = volume scattering coefficient

Ω = effective two-way beamwidth (solid angle expressed in radians),

and the other variables are identical to that of Equation (1).

Typically, the magnitude of S_v is in the range -60 dB to -90 dB (Urick, 1975). Assuming S_v = -60 dB and Ω = 10° and proceeding as in section 2, the range - target diameter relationship is found to be:

$$r = 435\ a \tag{5}$$

It should be noted from Equations (3) and (5) that the both systems have the same maximum range of 3154 m for spherical targets with a radius 7.25 m.

4. Active target

In this case a target is equipped with an acoustic transponder or pinger. The maximum range of such a system is limited by the ambient noise. The signal-to-noise ratio at the receiver is given by

$$\Delta_n = SL - (TL + \alpha r) - [NL - DI - 10 \log \tau] \tag{6}$$

where

SL = source level of the transponder,

α = absorption coefficient,

NL = ambient noise level at the operating frequency, f_0, and,

DI = receiving array directivity index.

For an array with a narrow azimuth beamwidth θ, the directivity index can be approximated by:

$$DI = 10 \log (4\pi/\theta\phi) \tag{7}$$

where, ϕ = receiving beamwidth in elevation (expressed in radians).

As a numerical example the following values for the system are assumed:

f_0 = 50 kHz,

τ = 10 m,

θ = 5°,

ϕ = 30°

For these values, the noise level (NL) at sea state 3 is approximately (Urick, 1975):

NL = 35 dB (re 1 μ Pa/ $\sqrt{}$ Hz)

and α = 11 dB/km

Assuming as before that the required Δ_n = 10 dB, Equation (6) reduces to:

$$20 \log r + 0.011 r = -40.6 + SL \qquad (8)$$

Assuming a signal level SL = 153 dB re 1μPa at 1 meter is achievable in a commercially available miniature pinger [Vemco Limited] and using Equation (8), the maximum range is found to be 3,700 m.

For a transponding pinger with an ommidirectional receiving beam pattern (DI = 0dB), the transmitted interrogations signal level must compensate for the loss of directionality given by Equation (7). The required transmitted signal level is therefore 24.4 + 153 = 177.4 dB re 1μ Pa, well below theachievable level of approximately 230 dB.

5. Active target detection through a bottom bounce

In certain situations (high waves) detection of an active surface target can be accomplished through an acoustic bottom bounce. Equation (6) for this situation becomes

$$\Delta_H = \Delta_n (r_0) - \alpha_B \qquad (9)$$

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where

$$r_0 = 2\sqrt{H^2 + (r/2)^2}.$$

In the above H denotes water depth and α_B denotes bottom reflection loss. The bottom loss depends on the bottom material, increases with frequency and grazing angle and varies typically from 10 to 25dB. Assuming α_B = 25 dB, H = 500 m and all other parameters the same as in section 4, the maximum range can be calculated using Equation 7 and found to be 1700 m.

6. Summary

Detection of small surface targets equipped with active transponders or pingers yield substantially longer detection ranges then it is possible with passive targets.

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